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# GEOLOGY AND UNDERGROUND WATERS

OF THE

# ARKANSAS VALLEY IN EASTERN COLORADO

BY

## N. H. DARTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1906

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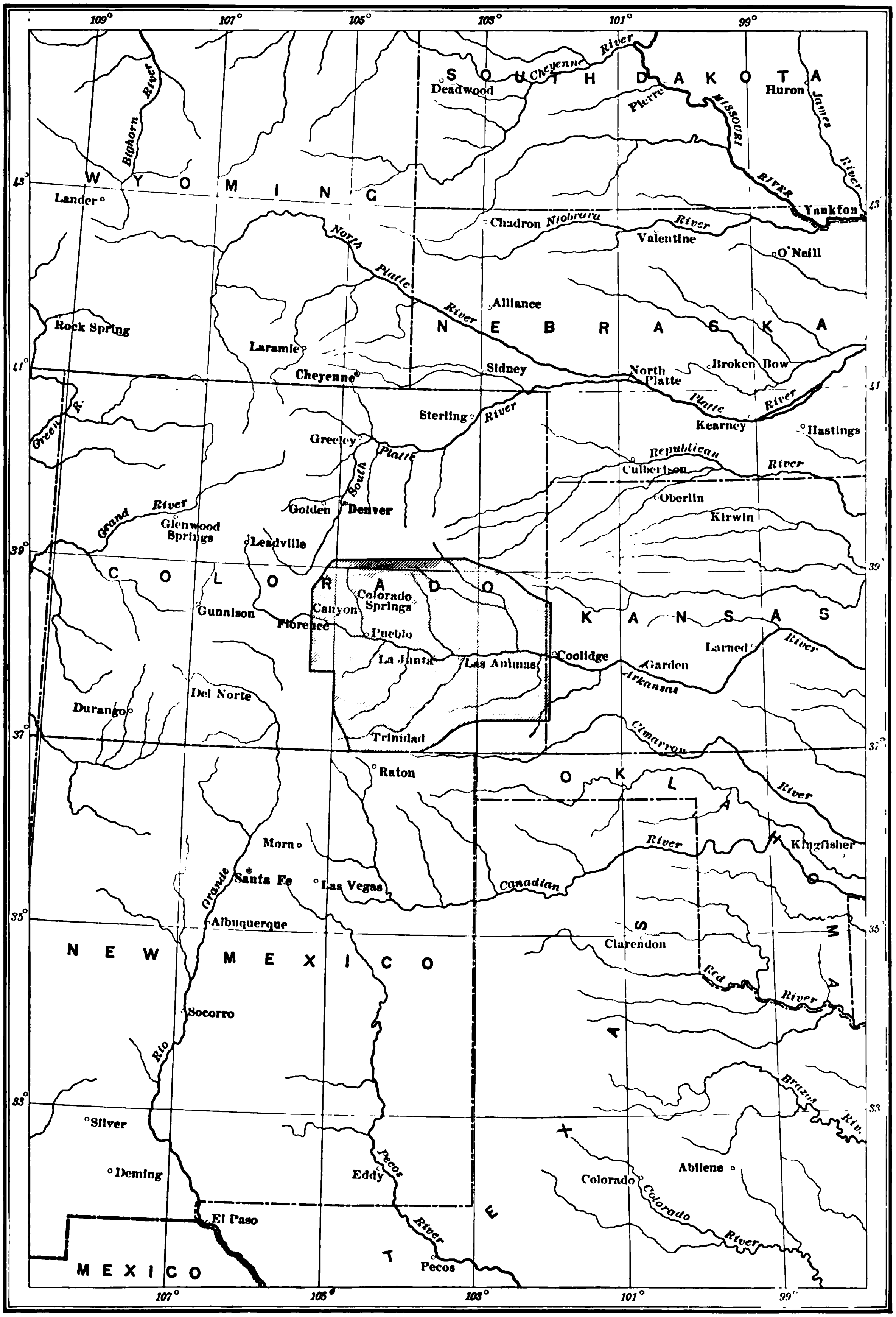

MAP OF CENTRAL WESTERN UNITED STATES, SHOWING AREA TREATED IN THIS REPORT

0 50 100 200 300 miles

# GEOLOGY AND UNDERGROUND WATERS OF THE ARKANSAS VALLEY IN EASTERN COLORADO.

### By N. H. DARTON.

## INTRODUCTION.

In the valley of Arkansas River in southeastern Colorado there is an area of considerable extent in which artesian flows are available. During the last ten years numerous wells have been sunk to develop this important resource and, in most cases in the lower lands, abundant water supplies have been obtained. The principal water-bearing bed is the "Dakota" formation, which consists of two sheets of porous sandstone separated by a small body of clay and overlain in the greater portion of the area by a mass of impervious shales. The sandstones receive their waters from rainfall and from the sinking of streams along the foothills of the Rocky Mountains and on some of the higher slopes south of the Arkansas Valley. In the passage of this sandstone underground, the waters which it contains are held down by the overlying shales, but, as some of the sandstone outcrops are at relatively low levels to the east only a moderate head or pressure is sustained. On account of this low head, artesian flows are available only in the lower lands, and one of the principal objects of this investigation has been the determination of the area in which flows are to be expected. The "Dakota" sandstone and associated formations do not lie level, or even slope regularly to the east, but are flexed into low arches and shallow troughs of considerable complexity of configuration. Accordingly, in investigating this source of water supply, it has been necessary to ascertain the structure and distribution of the various formations in order to indicate the variations in depth to the water-bearing stratum. The principal results of these investigations are set forth: (1) In the geologic map (Pl. VI), which shows the distribution of the formations on the surface; (2) in the map, Pl. XXV, which shows the depth to the water-bearing horizon, the area in which flows are expected, the head of the underground waters, and other features, and (3) in the cross sections (Pls. VII and XXIII), which show the principal underground features. The investigation has been in progress for several years and is an extension of the preliminary examination of the region by G. K. Gilbert in 1894 and 1895.[a]

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[a] Gilbert, G. K., Underground waters of the Arkansas Valley in eastern Colorado: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, pp. 1-51, Pls. LVI-LXVII.

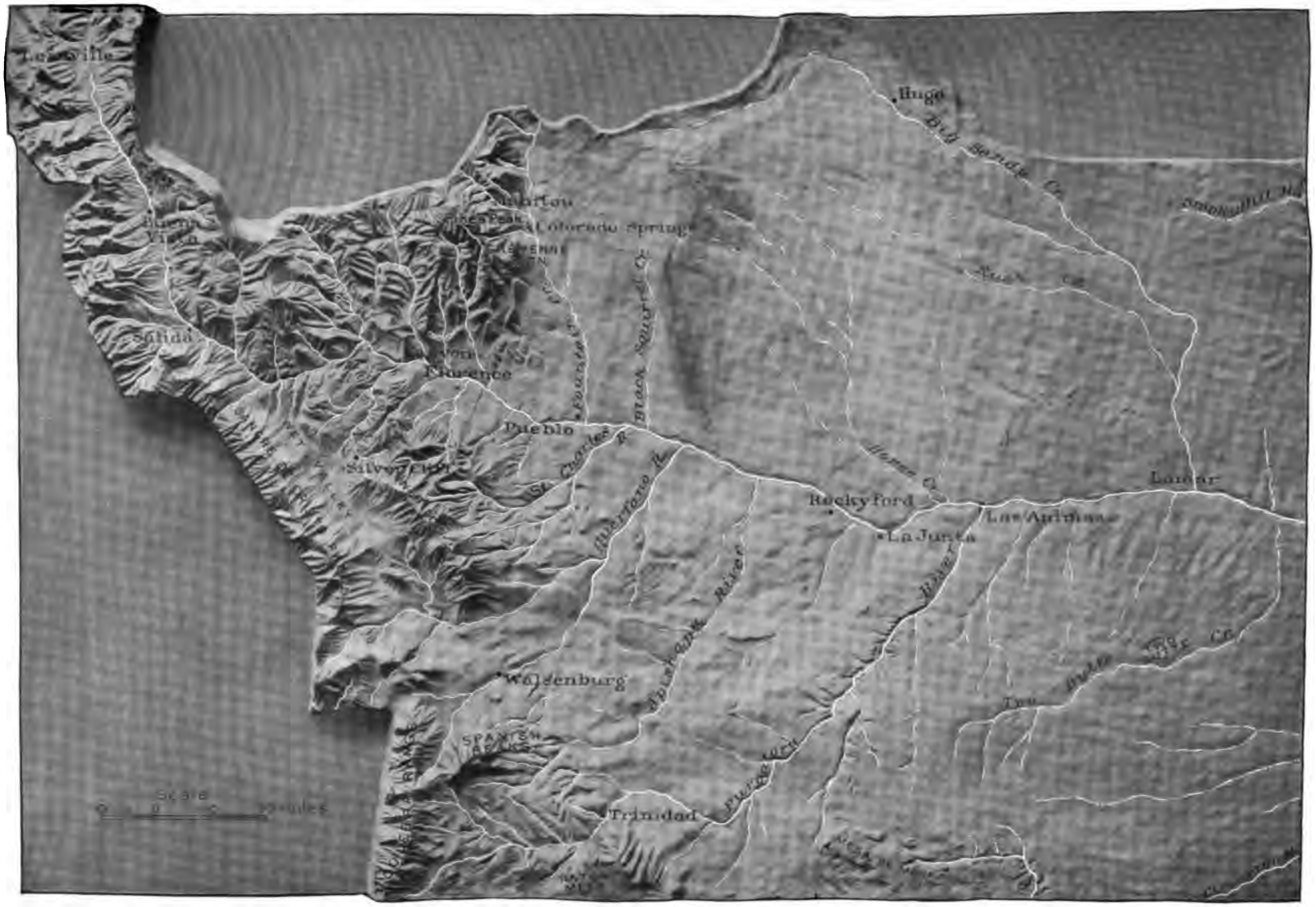
For the western portion of the area the maps and texts of the Pueblo, Elmoro, Walsenburg, Spanish Peaks, and Pikes Peak folios have been utilized as far as practicable. For the central and eastern portions the larger features of the geology have been specially mapped, and considerable detailed mapping has been done in the region south and southeast of Canyon and Colorado Springs. In the field work I have been assisted by Mr. C. A. Fisher, who has examined in detail the Nepesta quadrangle and contributed numerous other data. Dr. W. S. Tangier Smith and Messrs. C. E. Siebenthal and W. T. Lee have made observations in certain areas. Much valuable information respecting wells has been furnished by Mr. William Archer, of the Atchison, Topeka and Santa Fe Railway Company, and Mr. C. H. McVay, well driller at Rocky Ford.

## GENERAL CONFIGURATION.

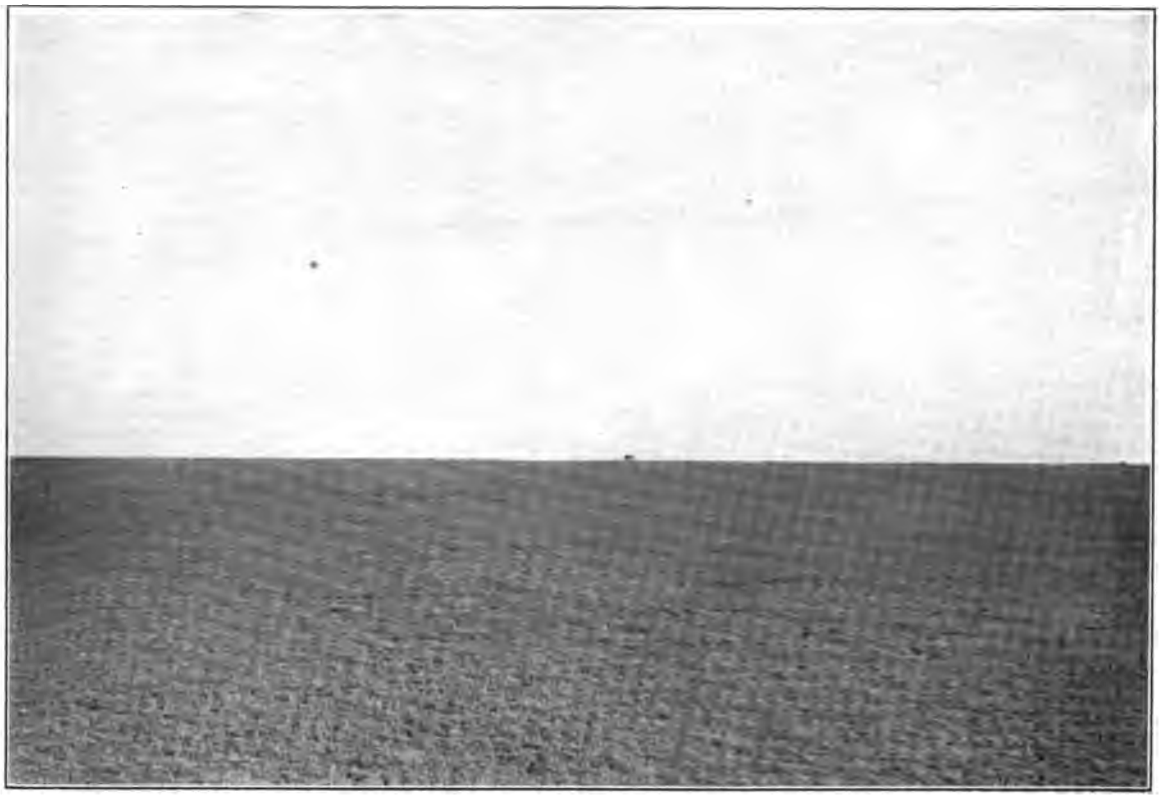
Eastern Colorado lies on the western portion of the Great Plains, which extend from the foot of the Rocky Mountains to the Mississippi Valley. These plains present wide areas of tabular surfaces traversed by the broad, shallow valleys of large rivers that rise mainly in the Rocky Mountains, and are more or less deeply cut by the narrower valleys of lateral drainage (Pl. II). Smooth surfaces and eastward-sloping plains are the characteristic features (Pl. III), especially of the uplands, but in portions of the region there are buttes, extended escarpments, and canyons of considerable depth. Local areas of sand hills occur, especially along the rivers and on some of the high plains, where there is much loose material that can be blown by the wind. The altitudes average about 6,000 feet at the foot of the mountains and about 3,500 feet along the eastern border of Colorado. Westward the mountains rise steeply to altitudes which reach over 14,000 feet in Pikes Peak, 13,600 feet in Spanish Peaks, and 12,300 feet in Greenhorn Mountain.

The principal streams of the region are South Platte and Arkansas rivers. These rise in the mountains, where they flow in deep canyons, but in crossing the plains their valleys are wide and average about 200 feet below the surrounding higher lands. Near the mountains the Arkansas Valley is bordered in places by cliffs of moderate height, but to the east the side slopes are very gentle. The altitude in the valley at the mouth of Royal Gorge is 5,400 feet; at Pueblo it is 4,675 feet, and at the Kansas line 3,350 feet. The average grade from Canyon to Pueblo is 15 feet to the mile, from Pueblo to La Junta, 8 feet, and from La Junta to the Kansas line, 7.3 feet.

The principal branch of Arkansas River in southeastern Colorado is Purgatory River, which rises in the Culebra Range and empties at Las Animas. The region adjoining this stream is one of unusual topography for the Great Plains; portions of it consist of sandstone plateaus cut by many canyons, that of Purgatory River being in places nearly 500 feet in depth. Other branches of the Arkansas crossing this plateau are Apishapa and Huerfano rivers, which have also cut canyons of considerable depth. Near the southern margin of the State there rise above the plains two large, prominent mesas—the Raton Mesa and the Mesa de Maya—both of which are due to thick sheets of volcanic rocks.



RELIEF MAP OF THE DRAINAGE BASIN OF ARKANSAS RIVER IN COLORADO.



*A.* THE HIGH PLAINS IN EASTERN COLORADO.

Grass, sunshine, and solitude.

*B.* VIEW ON THE GREAT PLAINS IN EASTERN COLORADO.

Shows ranch situated in shallow drainage basin.

## GENERAL GEOLOGY OF EASTERN COLORADO.

### GENERAL RELATIONS.

The eastern half of Colorado is underlain by an extensive series of sedimentary formations of late Cambrian to Tertiary age. They are in widely extended sheets, which lie nearly level under the plains, but are upturned steeply against the front ranges of the Rocky Mountains, in which the underlying granites and gneisses appear. The larger surface areas are the later Cretaceous and Tertiary formations, the latter covering much of the region north.

### STRUCTURE.

The general structure of the region is indicated in Pl. XXVI, which shows the configuration of the "Dakota" sandstone, not only in its surface outcrops, but also under the areas in which it is more or less deeply buried by younger formations. From this illustration it will be seen that there is, along the mountain front, a general steep monoclinal dip, which affects all of the formations except the youngest.

In greater part the monocline of the front ranges descends into deep basins, east of which the strata rise gently. The most extensive of these basins is one having its center near Denver. It extends from North Platte River to the Arkansas, and in its lower portion the granite and gneiss which are supposed to underlie the plains are 2,000 feet or more below sea level. This basin is terminated on the south by an anticline, which crosses the great offset and embayment in the mountain front west of Pueblo, and is a prolongation of the main Front Range of the Rocky Mountains. This anticline pitches downward very rapidly from a short distance south of Pikes Peak and crosses the Arkansas Valley a short distance west of Pueblo, beyond which it coalesces with a prominent anticline extending southeastward from the Wet Mountain Range. Between these two, in the vicinity of Florence, there is a deep synclinal basin lying in the sharp reentrant angle in the front of the Rocky Mountains. South of the eastward prolongation of the Wet Mountain anticline there is another deep basin occupying an area of considerable extent about the Spanish Peaks. The east side of this basin rises into an anticline of moderate prominence, which occupies a broad area in southeastern Colorado, coalescing with the extension of the Wet Mountain anticline to the northwest and extending far to the northeast, with considerable pitch, as the southeastern margin of the Denver basin. At Two Butte there is a small but prominent local uplift due to igneous intrusion.

These flexures affect all of the formations except the later Tertiary sands, gravels, and clays which cap the divides between the larger valleys. In the Denver and Spanish Peaks basins there are extensive deposits of all the formations up to the earlier Tertiary. In the Florence basin a small area of the Laramie occurs. The anticlines north and south of Pueblo are exhibited mainly in "Dakota" to Niobrara formations, and the wide anticline in the southeastern portion of the State presents extensive exposures of the "Dakota" sandstone, which extend to Arkansas River between Las Animas and the vicinity of Lamar.

## FORMATIONS.

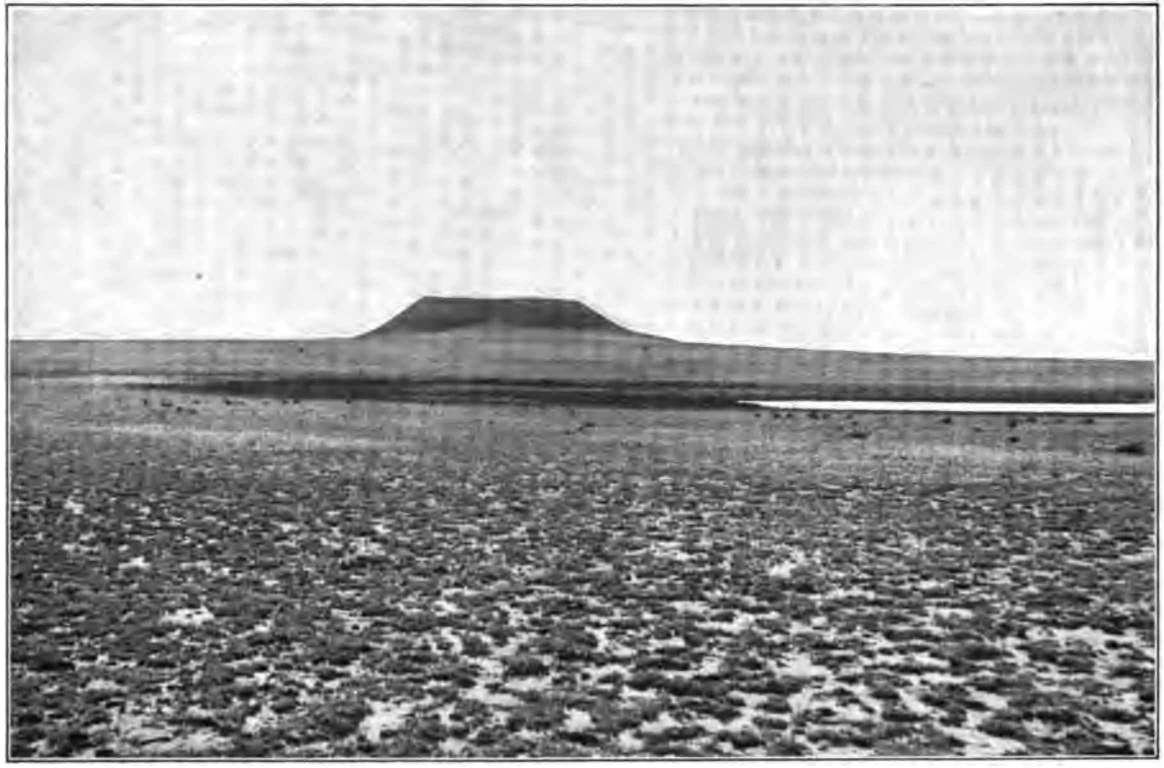
The sedimentary formations exposed in eastern Colorado represent a large part of geologic time from the later Cambrian to the present. Rocks of Silurian and Devonian age, however, are absent; the Ordovician and earlier Carboniferous appear only in small exposures; the Triassic may be absent in whole or in part; the earlier Jurassic is absent; the later Jurassic extends only a few miles into the northern portion of the State; a large part of the earlier Cretaceous is absent; and there are a number of short breaks in the early, middle, and latest Tertiary times.

Rocks of later Cambrian age appear at a number of points along the Front Range, mainly in small embayments west and northwest of Colorado Springs and north of Canyon, but it is possible that these are projections from a more extended sheet which may underlie the plains eastward. It is evident that the Rocky Mountain Front Range was originally a shore line of irregular contour on which varying degrees of submergence caused an irregular sequence of overlaps. The later Cambrian rocks are sandstones, evidently representing a shore deposit which originally had an irregular western margin, much of which is now buried under later overlapping sediments.

The Ordovician rocks, which consist mainly of limestones (Manitou and Fremont), with an intervening local sandstone (Harding), are also of restricted occurrence. Outcrops appear in Perry Park, west and north of Colorado Springs, west and north of Canyon and Florence, south of Canyon, and southwest of Pueblo. At most localities they are overlain unconformably by the Millsap limestone, of earlier Carboniferous age, which presents irregular overlap relations from point to point. These formations probably extend continuously under the Great Plains, but they have not been reached by any borings in eastern Colorado.

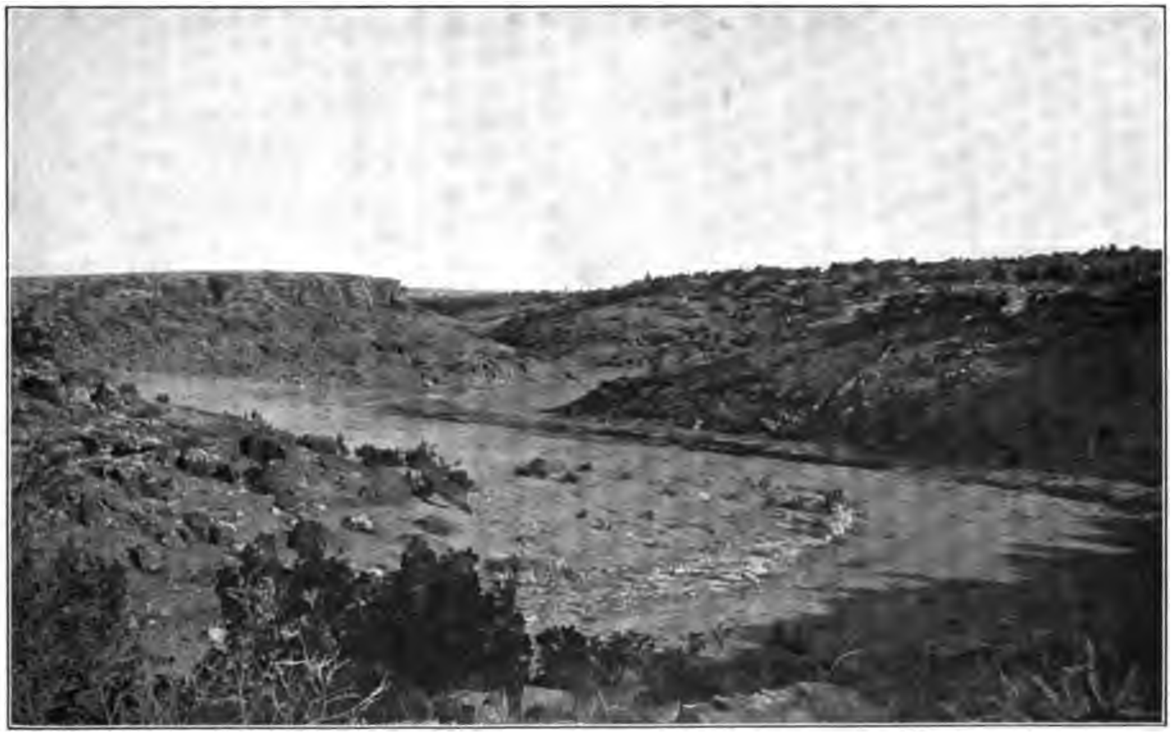
One of the most prominent members along the Rocky Mountain front is the great succession of "Red Beds" which lie on an irregular surface of the granites, except in some of the embayments where Cambrian, Ordovician, and earlier Carboniferous rocks intervene. They have been found to be an extension of the "Red Beds" and underlying Carboniferous limestone of southeastern Wyoming and of the Permian and overlying "Red Beds" of southern Kansas. They are readily divisible into three members. The lowest is the Fountain formation, or lower Wyoming. This consists of coarse, red grits, which I have found represent the Upper Carboniferous limestones of Wyoming. The second is the Tensleep sandstone, or "Creamy sandstone" of Eldridge, which has been traced as far south as the Manitou embayment. The third member consists of the gypsiferous red shales and sandstones known as the Chugwater formation, and is believed to represent the "Red Beds" of eastern Wyoming and the Black Hills. The lower beds of this member are of Permian age and the upper beds are either Permian or Triassic. It appears to terminate a short distance southwest of Colorado Springs. The "Red Beds" underlie the plains in eastern Colorado and have been reached by several deep wells in the Arkansas Valley and by some of the deeper canyons farther south.

The marine Jurassic, which is well characterized in eastern Wyoming, extends only a short distance south into Colorado, where it thins out, but the unconformity



*A.* HAYSTACK BUTTE, PUEBLO COUNTY, COLO.

Typical flat-topped outline of Timpas limestone or Carlile shale.



*B.* APISHAPA CANYON NORTHWEST OF THATCHER, COLO.

A typical sharp-edged flat-bottomed canyon in "Dakota" sandstone.

by which it is separated from the "Red Beds" northward continues to the south, and represents, throughout the greater part of eastern Colorado, all of Jurassic and probably also some of Triassic time. Above this unconformity lies a widespread sheet of fine-grained sediments known as the Morrison formation, evidently of fresh-water origin and supposed to represent part of the earlier Cretaceous time. It is usually less than 300 feet thick, but appears to underlie all of eastern Colorado, although thinning considerably eastward.

The Morrison shales and clays are followed by a succession of coarse-grained sandstones, usually designated the "Dakota" sandstone, consisting of two principal masses with an intervening deposit of fire clay, having in all a thickness averaging 300 feet. This series underlies all of the eastern part of Colorado, appearing prominently along the slopes of the Front Range and widely in the anticlinal uplifts south of Arkansas River. Its upper member undoubtedly represents the "Dakota" sandstone, but the medial clay and the lower sandstone series probably represent, respectively, the Fuson and Lakota formations, two Lower Cretaceous members of the Black Hills. The remarkable uniformity of this tripartite succession and its intimate association with the underlying Morrison beds is a most significant feature over a wide area of the Rocky Mountain province. Several years ago fossils of Comanche age were found in the medial, or fire-clay, member in the southeast corner of the State, and recently Mr. T. W. Stanton has obtained these fossils at this horizon at various localities as far west as Canyon.

The "Dakota" sandstone is succeeded abruptly by a great succession of marine sediments, mainly shales, with limestones at certain horizons, representing a long interval of later Cretaceous time. The lower portion of this succession consists of the Benton group, which is from 400 to 500 feet thick in greater part and comprises two shale formations separated by one of limestone. Its character is constant throughout nearly a half million square miles of the central Great Plains. The rocks of the Benton group are exposed in a narrow zone all along the Rocky Mountain front and in extensive areas along the slopes of the anticlinal uplifts south of Arkansas River. They are succeeded by the calcareous deposits of the Niobrara, which attain their greatest development in eastern Colorado. The usual succession in the Niobrara is a lower limestone and an upper series of limy shale, which in portions of the Arkansas Valley attain a thickness of nearly a thousand feet. The Niobrara formation is extensively exposed in the Arkansas Valley east of Florence.

Overlying the Niobrara formation is a thick mass of clay known as the Pierre shale, which has a wide extent and great thickness in the Denver basin, in the southern end of which it extends as far south as Arkansas River east of Pueblo. A smaller area occurs in the Spanish Peaks syncline, and a still smaller one in the Florence basin, where it is the source of petroleum. West of Denver the Pierre formation appears to have a thickness of more than 7,500 feet; about Florence it is more than 3,000 feet thick; and in the Spanish Peaks syncline its greatest amount appears to be not more than 2,000 feet. The formation thins rapidly in eastern Colorado, where its surface has been extensively eroded in earlier Tertiary times. It consists of a succession of dark shales, with occasional beds of sandy shales and sandstones, and usually contains abundant remains of marine shells.

The Pierre shale gives place rapidly to the Fox Hills formation, which in greater part consists of sandstones, and this, in turn, is succeeded by the Laramie formation, a thick succession of sandstones and sandy shales containing extensive and valuable deposits of lignite. The latter formation is of fresh-water origin and represents the product of late Cretaceous time. It occupies a broad area in the Denver basin, in which it extends southeastward from Colorado Springs and northeastward into Wyoming and Nebraska. There is a large area of it in the Spanish Peaks basin and a small area in the Florence basin.

In the two larger basins above mentioned the Laramie deposits are overlain by extensive beds, mainly of conglomerates and sandstones, which may possibly represent the earliest deposits of Tertiary time. Several formations separated by unconformities are comprised in this series, and they constitute the greater part of the elevated region culminating in the Spanish Peaks.

There probably is a considerable interval of early and middle Tertiary time not represented by deposits in eastern Colorado. The White River group of Oligocene age caps the Laramie formation in the northeast corner of the State and occupies an area of considerable extent in the highlands south of Denver, where it is known as the Monument Creek formation. These Oligocene deposits consist of sands, sandstones, and clays, which probably were once of considerably greater extent in eastern Colorado, but were removed by later Tertiary erosion.

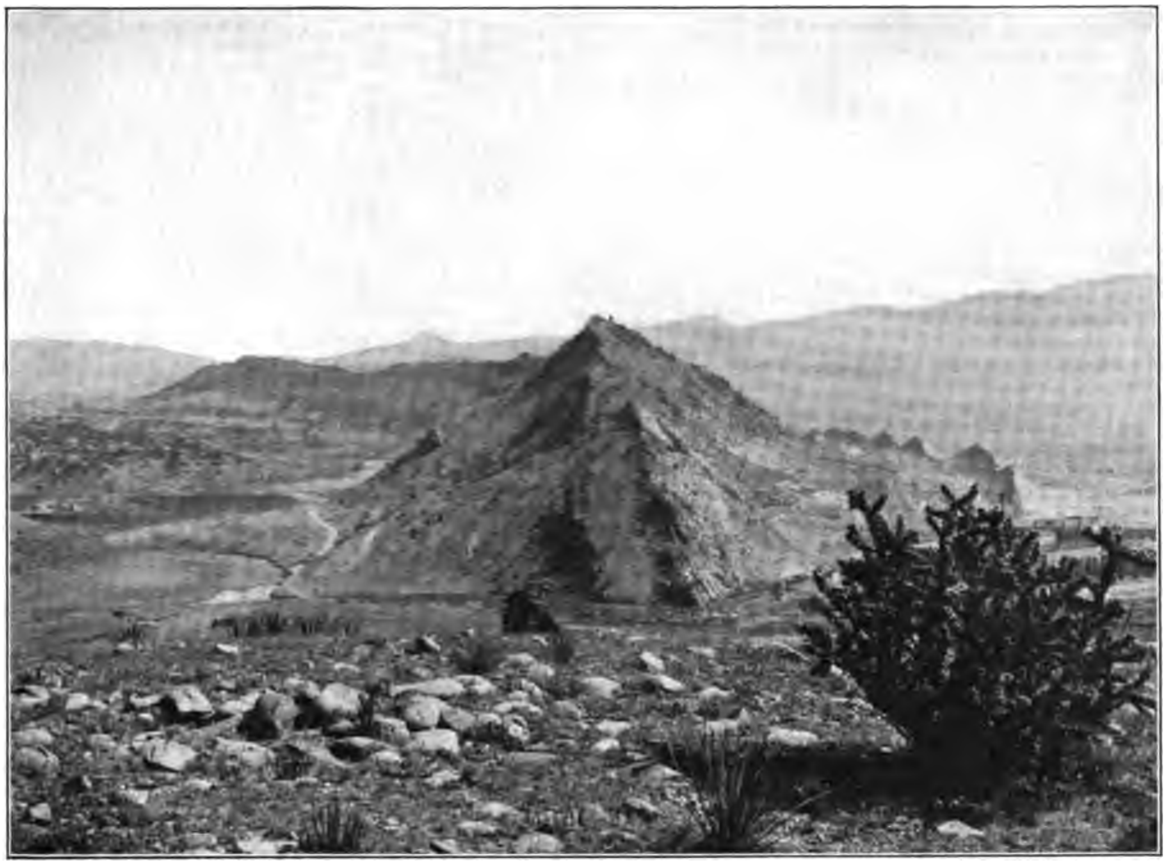
On the principal divides in the eastern portion of Colorado there are wide areas of the original high plains capped by later Tertiary deposits, consisting of sands and gravels, often locally cemented into a limestone grit. This formation has been extensively removed along the valleys of Platte and Arkansas rivers, but originally it probably extended to the foot of the higher mountain slopes, as it does in Wyoming. The age of this covering of the old high plains is believed to be Pliocene, but in the northeastern portion of the State there is also an underlying member, the southern extension of the Arikaree formation, which lies on the White River formation for some distance.

The Quaternary system in eastern Colorado is represented mainly by the alluvial deposits along the valleys and by some remnants of earlier terraces of moderate elevation.

## GEOLOGY OF THE ARKANSAS VALLEY REGION.

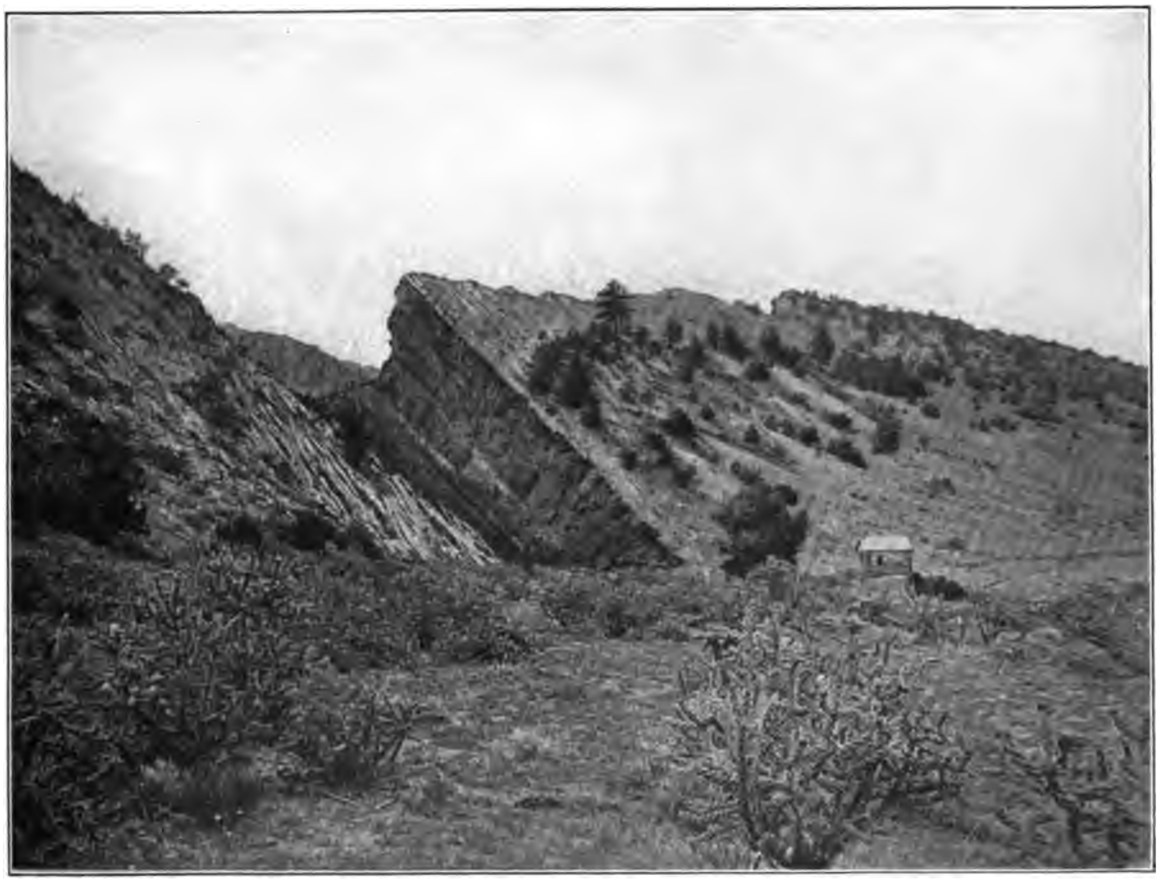
### STRATIGRAPHY.

The sedimentary formations exposed in the area drained by Arkansas River in eastern Colorado are mainly of Cretaceous age, but along the slopes of the Rocky Mountains an extensive series of older formations lies on granite. The various formations of Cretaceous age present extensive exposures, but the older formations outcrop only in small areas, and there are among them many irregular overlap relations, due to the unevenness of the surfaces on which they were laid down. The most extensive developments of the older rocks are in the embayments north of Canyon and west of Colorado Springs.



*A.* "DAKOTA" HOGBACK AT CANYON, COLO.

Valley of "Red Beds" and slopes of Morrison beds to left; minor hogbacks of Timpas limestone to right. Photograph by I. C. Russell.



*B.* "DAKOTA" HOGBACK RIDGE 2 MILES SOUTHWEST OF CANYON, COLO.

Looking north. Valley of Graneros shale in foreground; mountains of gneiss in distance. Photograph by C. D. Walcott.

*Table of geologic formations of southeastern Colorado.*

| Age. | Formations. | | Principal character. | Thickness. |
|---|---|---|---|---|
| | | | | *Feet.* |
| Quaternary | | | Sand, gravel, and loam | 50 |
| | | | Higher terraces, sand, gravel, and loam | 50 |
| Tertiary | Nussbaum-Ogalalla | | Sand, gravel, and conglomerate | 150 |
| | Monument Creek | | Sand, gravel, and clay | 200 |
| | Huerfano | | Coarse sandstone and conglomerate on clays and marls. | 2,900 |
| Cretaceous(?) | Cuchara (Denver) | | Massive sandstone; some clay | 475 |
| | Poison Canyon (Arapahoe) | | Sandstone conglomerate; some clay | 1,900 |
| Cretaceous | Laramie | | Gray sandstone and shale | 2,000 |
| | Trinidad sandstone (Fox Hills) | | Massive sandstone | 150 |
| | Pierre | | Dark-gray shale with concretions | 1,300-3,000 |
| | Apishapa | Niobrara group | Sandy shale, thin beds of limestone near top | 550 |
| | Timpas | | Limestone and limy shale | 200 |
| | Carlile | Benton group | Dark shales with sandstone at top | 200 |
| | Greenhorn | | Slabby limestone; shale partings | 50 |
| | Graneros | | Dark shales | 200 |
| | "Dakota" | | Gray sandstone, fire clay in middle | 200- 300 |
| | Comanche series | | Soft sandstone and sandy clays | 20 |
| | Morrison | | Gray to maroon joint clays with limestone and sandstone layers. | 200 |
| Triassic (?) and Permian | Chugwater | | Bright-red sandy shales with thin limestone layers and gypsum; reddish sandstone at top. | 100 |
| Carboniferous: Pennsylvanian | Tensleep, | Lower Wyoming | Fine-grained massive sandstone | 200 |
| | Fountain (Badito) | | Coarse red sandstone and conglomerates | 600-1,200 |
| Lower Mississippian | Millsap | | Gray and purplish limestone | 20- 200 |
| Ordovician | Fremont | | Gray to pinkish dolomite, uneven grain | 100 |
| | Harding | | Fine, even-grained, gray to pink sandstone; some shale. | 100 |
| | Manitou | | Reddish dolomite | 100- 270 |
| Cambrian | | | Reddish sandstone | 40- 100 |

## CAMBRIAN SYSTEM.

In the Manitou embayment west of Colorado Springs and in a small area north of Canyon rocks of Cambrian age appear lying on the granites. The deposits north of Canyon consist of a thin mass of sandy and cherty beds of variable local development at the base of the Manitou limestone. They have yielded a trilobite, *Ptychoparia,* a form of Upper Cambrian age. In the Manitou embayment west and northwest of Colorado Springs the Manitou limestone is nearly everywhere underlain by 10 to 80 feet of sandstones, mostly of pinkish color, containing Upper Cambrian fossils. Some of these were obtained by Doctor Cross from the east branch of Trout Creek, 45 feet above the granite; they comprised *Lingulepis* sp. (?) and a *Lingula* of elongate form allied to *pinnæformis* of the Upper Cambrian of Wisconsin.

This sandstone appears at Manitou and extends northward along the west side of the Garden of the Gods to beyond Glen Eyrie, where it contains upper Cambrian fossils. One section which has been reported has, beginning at the base, 26 feet of greenish-white sandstone, 4 feet of coarse dark-green sandstone, 6 feet of coarse gray sandstone, and 20 feet of brick-red sandstone with green layers, overlain by Ordovician limestone. A small area containing fossils was found southwest of Monument Park, and, according to Mr. W. T. Lee, a quartzite which is presumably of the same age appears on Deadman Creek south by west from Monument station.

### ORDOVICIAN SYSTEM.

Rocks of Ordovician age are extensively exposed in the embayment north and northeast of Canyon and west of Colorado Springs, and two small areas have recently been observed southwest and south of Canyon. They consist of limestones and sandstones usually lying on a thin deposit of Cambrian sandstone, or quartzite, and sometimes they overlap on the granite and schists. In the Canyon district the Ordovician is represented by the Manitou limestone, Harding sandstone, and Fremont limestone (Pl. V, *A*). These have been described in detail by Dr. C. D. Walcott,[a] mainly in connection with the occurrence of fish remains, and by Dr. Whitman Cross in describing the region northeast of Canyon in the Pikes Peak folio. The following members are described by Doctor Cross:

*Manitou limestone.*—This limestone is extensively exhibited in Oil Creek Valley, Garden Park, where it consists of fine-grained pink or reddish dolomite less than 100 feet thick. It occurs in the Manitou region, where it contains *Ophileta*, *Camerella*, and other characteristic Ordovician fossils.

*Harding sandstone.*—This formation consists mainly of fine, even-grained, granular sandstone in alternating bands of light-gray and pinkish or variegated colors, with a few bands of dark-red or purplish sandy shale, having a maximum thickness of about 100 feet (Pls. VIII and XIX,). The lower part is sometimes calcareous and develops into a thin fine-grained dolomite. This formation contains fish remains at the Canyon locality. In Garden Park the sandstone rests with apparent conformity on the Manitou limestone, but to the southeast it overlaps on the basal sandstone and near Canyon on the gneiss. At Canyon the formation is 86 feet thick and consists of gray, reddish, and purplish-brown sandstone and shales with many fossils of early Trenton age. A small outlier of sandstone, apparently of this formation, underlying the Millsap (Carboniferous) limestones in the slopes west of Beulah, is mapped by Gilbert in the Pueblo folio.

*Fremont limestone.*—Overlying "the Harding sandstone with apparent conformity, there occurs a bluish-gray or pinkish dolomite of uneven grain, sometimes arenaceous, which gives rise to very rough weathered surfaces." Its thickness in Garden Park is about 100 feet, but increases southward to a maximum of 270 feet near Canyon, partly through the development of an upper fossiliferous member. In Garden Park it is characterized especially by the coral *Halysites catenulatus*, and also contains a molluscan fauna like that of the upper Trenton in New York. It appears to be restricted to a small area in Garden Park and vicinity and a narrow outcrop extending southward past Canyon. These formations all end a short distance southwest of Canyon by overlap of later deposits, but two small areas were found, one near the road 4 miles southwest of Canyon and another at the foot of the mountain on one of the branches of Chandler Creek, 7 miles nearly due south of Canyon.

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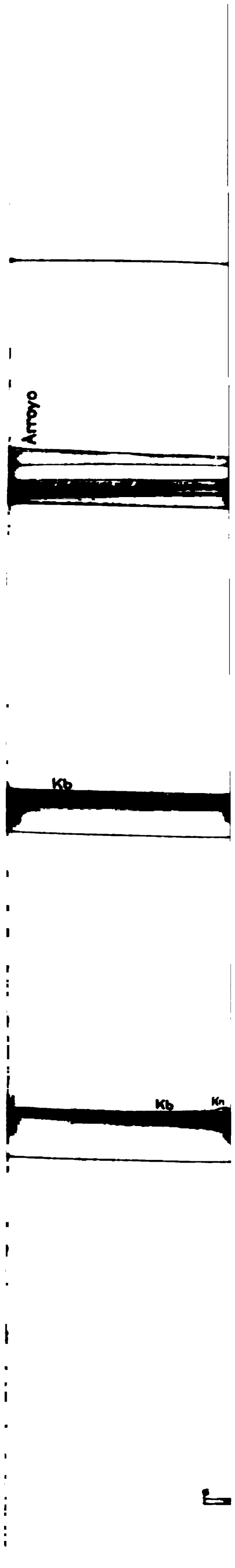
[a] Bull. Geol. Soc. America, vol. 3, pp. 153-167.



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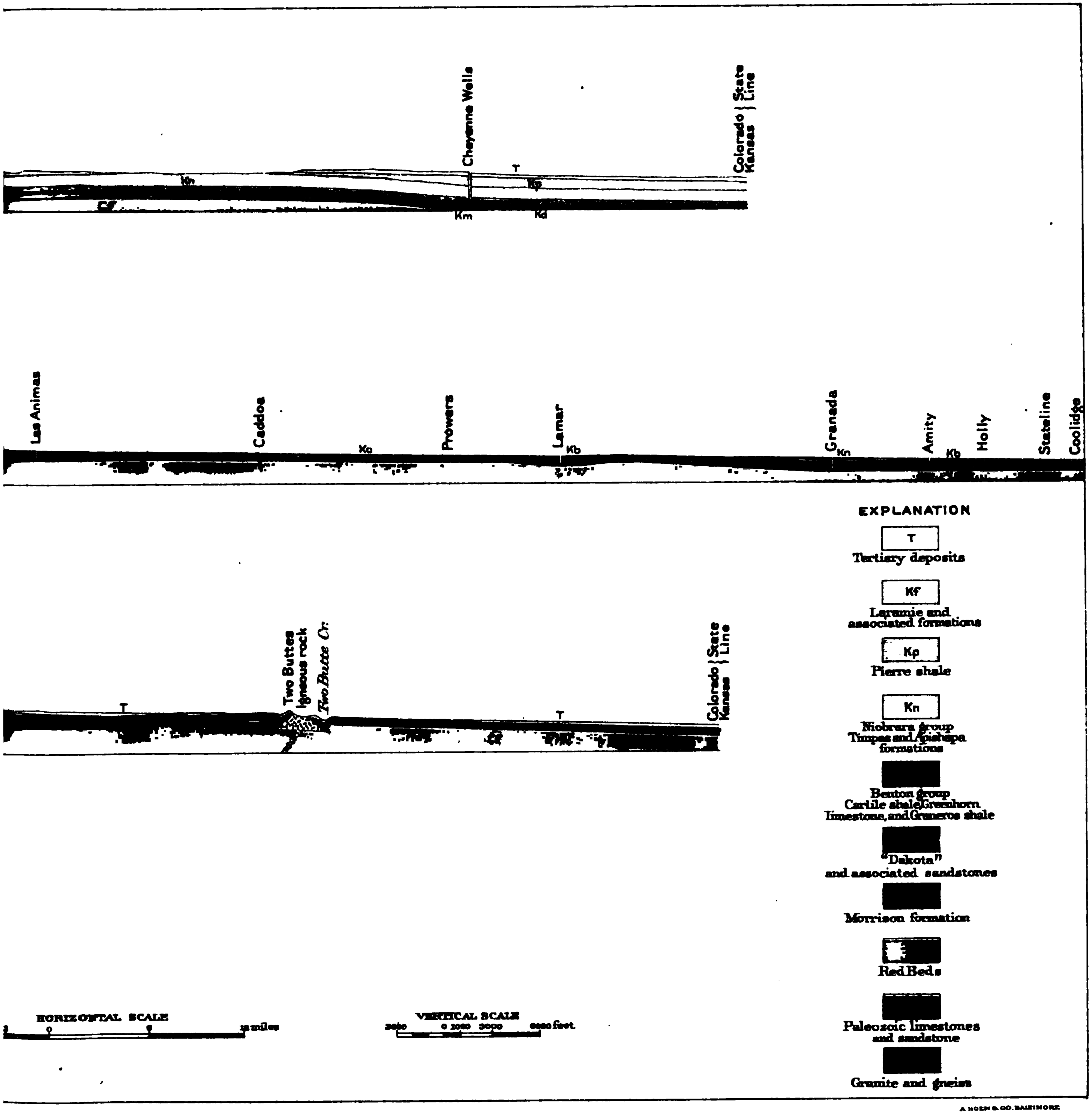

ORADO

A. HOEN & CO. BALTIMORE

At Manitou and for some distance northward and in the Trout Creek Valley (Manitou Park) there are other areas of Manitou limestone underlying the "Red Beds." On Trout Creek this limestone has yielded distinctive Ordovician fossils.

Doctor Peale gives the following section of the exposure of Manitou limestone and associated formations at Glen Eyrie:[a]

*Geologic section of basal rocks near Glen Eyrie, Colo.*

| Age. | Description. | Thickness. |
|---|---|---|
| | | *Feet.* |
| Carboniferous (?) | Gray, purplish, and yellow limestones | 279 |
| Ordovician | Red shaly limestones, with fragments of Ordovician fossils | 4 |
| | Limestones with interlaminated shales | 7 |
| | Red limestone with flint nodules | 7 |
| | Red limestone | 2 |
| | Red shaly limestone | 1 |
| | Red limestone | 1 |
| | Irregularly laminated limestone | 3 |
| | Red and greenish limestone | 5 |
| Cambrian | Brick-red sandstone with green layers | 20 |
| | Coarse gray sandstone | 6 |
| | Coarse dark-green sandstone | 4 |
| | Coarse grayish-white sandstone | 20 |
| | Granite. | |

On Deadman Creek, 6 miles south of Perry Park, a small outlying area has been investigated by Mr. Willis T. Lee.[b] The rocks are cherty limestones in layers interstratified with red clay, overlying a few feet of deep-red quartzite of supposed Cambrian age. The fossils obtained were examined by Doctor Weller, who found the best preserved specimens to be *Dalmanella testudinaria* of Ordovician age.

## CARBONIFEROUS AND TRIASSIC SYSTEMS.

*Millsap limestone.*—This limestone of Lower Carboniferous age appears in a few isolated outcrops west of north of Canyon and west of Colorado Springs. North of Canyon it lies on the Fremont limestone and is immediately overlain by the "Red Beds" of the Fountain formation. The locality in which the largest amount is exposed is in the angle between Oil and Millsap creeks, where there are about 30 feet of thinly bedded, variegated, dolomitic limestones, with a few thin sandstone layers. Chert nodules in the upper limestones carry casts of *Spirifera rockymontana* and *Athyris subtilita.* The limestone appears at several points among the outcrops on the slope of the mountain northwest of Canyon. In the limestone area west of Colorado Springs, fossils of Carboniferous age have been discovered by Prof. A. W. Grabau. In a letter Professor Grabau states that they are remains of *Spirifer,* either *rockymontana* or *centronatus,* and small producti. They occur in a light-gray, compact limestone about 10 feet thick, lying from 10 to 15 feet below reddish and purplish shaly beds at the base of the Fountain formation. About 100 feet lower some other remains were found which were not determined.

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[a] Peale, A. C., Geology of the South Park division: Seventh Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1874, p. 201

[b] Lee, W. T., Geology of the Castle Rock region, Colorado: Am. Geologist, vol. 29, pp. 96-97.

A small area of this limestone appears on the slopes west of Beulah, as described by Mr. Gilbert. In this locality its thickness is 200 feet and it consists of gray and purplish limestone with some shale in its lower part. *Spirifera rockymontana* occurs near its middle. It lies on supposed Harding sandstone, the Fremont limestone apparently being absent.

*The "Red Beds."*—The most conspicuous sedimentary formations exposed along the Rocky Mountain Front Range is the succession of red sandstones known as the "Red Beds." For the greater part of their course they lie directly on the granite, but in the embayment about Manitou and Canyon they are locally underlain by limestones. Near the Arkansas divide, at Palmer Lake, they are overlapped by Monument Creek beds; west of Monument, southwest of Colorado Springs, and south of Canyon, they are faulted down, and southwest of Pueblo they are locally overlapped by the Dakota and associated formations. The thickness of the "Red Beds" is variable, but it is rarely less than 1,000 feet, and in the Garden of the Gods it is greater. Part of the variation is due to the uneven floor, the thicker masses of the beds lying in the deeper depressions. The "Red Beds" are also exposed extensively in the Purgatory and other deep canyons in the High Plains south of Arkansas River. The rocks are mainly coarse-grained red grits and red sandstones.

In the Manitou embayment there are three divisions of the "Red Beds." The uppermost consists of about 100 feet of red shales, a thick bed of gypsum, and thin beds of limestone, and is believed to represent the Chugwater formation of eastern Wyoming (upper Wyoming beds). The medial member consists of about 200 feet of fine-grained, light-colored, massive sandstone, which in the Boulder region has been designated the Lyons sandstone by Professor Fenneman.[a] The lowest formation, the Fountain, is about 1,000 feet thick and consists of coarse red grits. In southeastern Colorado the upper part of the "Red Beds" consists of gypsum and red shales, which may represent the Chugwater (Lykens) formation; as yet, however, no evidence has been found on which to base correlation.

The "Red Beds" are extensively exposed in the Garden of the Gods and for some distance north and south, dipping nearly vertical. At the south they are cut off by the great fault which passes along the base of Cheyenne Mountain. They give rise to the picturesque features of the Garden of the Gods, the Gateway marking the outcrop of the uppermost hard red stratum. Next above these are some softer striped red sandstones, about 100 feet thick, not well exposed at the Gateway, and then the white sandstone which outcrops a short distance east of the Gateway. This last bed is about 100 feet thick, moderately fine grained, massive, and cross-bedded, and represents the "Creamy sandstone" of Eldridge (or the Lyons sandstone of Fenneman), at the top of the lower Wyoming. The occurrence of this lighter colored, finer grained sandstone at this horizon is general along the foothills of the Rocky Mountains from Manitou north, and in the Laramie Range, Black Hills, and Bighorn Mountains, being the Tensleep sandstone of the Bighorn slopes. Near the Garden of the Gods it is similarly succeeded abruptly by soft, red shales, including near the base thin limestones believed to represent the Minnekahta limestone and gypsum deposits above, and extending to typical

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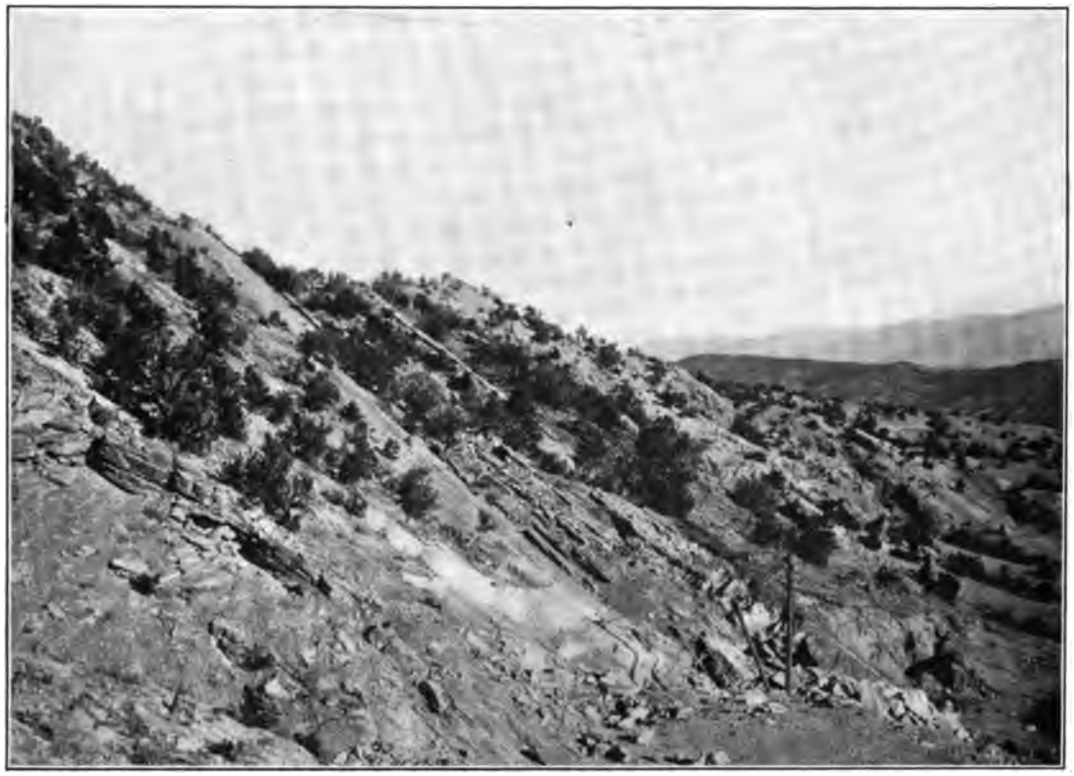
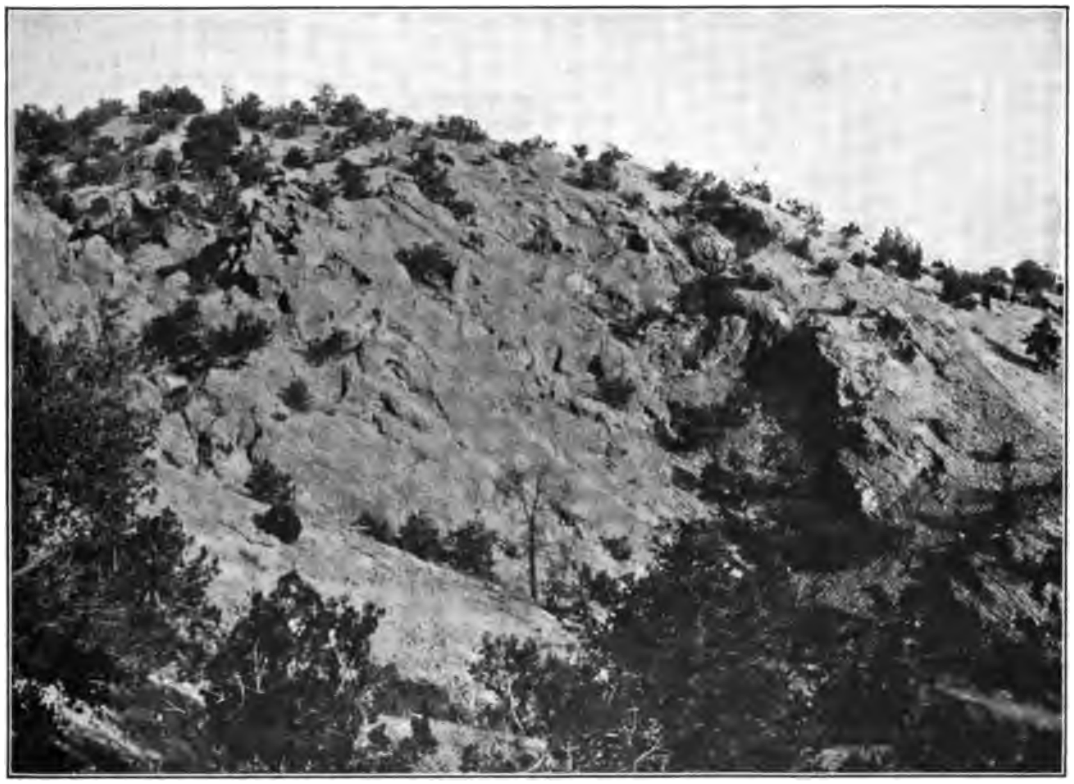
[a] Bull. U. S. Geol. Survey No. 265, 1905.



*A.* QUARRY IN HARDING SANDSTONE ON EAST SLOPE OF MOUNTAINS 2½ MILES NORTHWEST OF CANYON, COLO.

Looking north Granite to left, Harding sandstone in quarry, Fremont limestone and "Red Beds" in slopes to right. Photograph by C. D. Walcott.



*B.* FREMONT LIMESTONE NORTHWEST OF CANYON, COLO.

Shows irregular erosion forms.

Morrison shale. This upper series of red shales, limestones, and gypsum undoubtedly is equivalent to the upper Wyoming of Eldridge (or Lykens formation of Fenneman). At its base, overlying the white sandstone, are 55 feet of soft, red shale and red clayey sandstone (Opeche horizon), 25 feet of thin limestone layers with red shale intercalations (Minnekahta), and 30 feet of red shales surmounted by a 30-foot bed of gypsum ovelain by Morrison shales. The following section was measured a short distance north of the Gateway to the Garden of the Gods:

*Section of the upper "Red Beds" between the Gateway of the Garden of the Gods and Glen Eyrie.*

| | | Feet. |
|---|---|---|
| Clays and shale (Morrison). | | |
| Upper Wyoming beds: | | |
| Gypsum | | 30 |
| Red shales | | 30 |
| Limestone | (Minnekahta) | 3 |
| Red shales with thin limestones | | 22 |
| Purple limestone, thin layers | | 1 |
| Soft red shale and sandstone (Opeche) | | 55 |
| Top of lower Wyoming beds: | | |
| Massive white sandstone (Lyons or Tensleep). | | |

To the south the "Red Beds," both upper and lower, preserve the same general features to the great fault at the foot of Cheyenne Mountain, though showing local variations. At the Gateway the 30-foot bed of gypsum is a conspicuous feature, and there is a thin bed of gypsum a short distance below its base. Just below the Gateway these beds are offset and twisted, so that they are locally deflected some distance west of the general line of strike. On the roadside south of the Gateway there are seen very coarse, cross-bedded materials in the upper part of the Fountain formation, giving place abruptly to the fine-grained red sandstones and red gypsiferous shales of the upper Wyoming, all vertical or dipping steeply eastward, as shown in Pl. IX, *A*.

In the railroad cut in the western portion of Colorado City the following section is exposed:

*Partial section of "Red Beds" at Colorado City.*

| | Feet. |
|---|---|
| Sandy shales, etc. (Morrison). | |
| Talus and "Red Beds" | 50 |
| Impure gypsum | 5 |
| Red shales and soft sandstone with 3 feet of thin beds of gypsum near top | 60 |
| Soft, massive, red sandstone | 55 |

The section consists of upper Wyoming "Red Beds," except that the basal member may possibly be the upper part of the Lyons.

When the "Red Beds" next appear, beyond the fault southwest of the village of Fountain, they are seen to consist, after the first 1 or 2 miles, almost entirely of coarse-grained materials without the uppermost gypsiferous red shales and to be overlain directly by Morrison beds. This coarse deposit, constituting the entire "Red Bed" section of this region, was designated the Fountain formation by Cross, a name which has been employed by Gilbert in the region still farther south. Here, as in the Manitou and Perry Park embayments, it is underlain by Millsap limestone.

The Fountain formation in the region extending from southwest of Fountain to Canyon consists mainly of coarse-grained, crumbling, arkose sandstone in massive beds, usually cross-bedded. Many conglomeratic streaks occur and a basal conglomerate often appears, notably on the road northwest of Canyon, where it lies on an eroded surface of Millsap limestone (Pl. XX). The beds are prominently reddish, but some are gray and others are mottled gray and red. Finer grained materials, nearly all of a bright brownish-red color, often occur. The thickness is estimated as 1,000 feet, but varies considerably. Nearly everywhere the formation is separated from the granites and gneisses by limestones of Ordovician age, but in places it overlaps the crystalline rocks, and at some localities the underlying limestones are faulted out. In the vicinity of Canyon and at a small locality on Cripple Creek at the head of Garden Park the underlying Millsap limestone appears. In the region southwest of Pueblo the thickness of the Fountain formation, as measured by Mr. Gilbert, is 2,100 feet, including practically all of the formation, but it thins out to the southward and is absent for some distance along the foot of Greenhorn Mountain.

At the south end of Greenhorn Mountain there appears a similar succession of rocks which Mr. Hills has named the Badito formation, probably corresponding to the Fountain formation. It comprises an upper member, about 100 feet thick, generally massive or thick-bedded, but sometimes shaly on the weathered surface, and a lower member, of about the same thickness, of very coarse brownish-red conglomerate. Lying on granites and gneisses to the south this succession appears again in the Culebra Range, where it expands to a great thickness. The Carboniferous limestones appear again on this range about Veta Pass, and they extend southward into New Mexico. This area was described in considerable detail by Mr. Endlich, of the Hayden Survey, who mapped the lower portion of the series as "Lower Carboniferous," and several thousand feet of "Red Beds" as "Upper Carboniferous."

In 1902 Mr. Willis T. Lee[a] collected fossils and made a section southwest of Spanish Peaks. These fossils, obtained mostly from the lower hundred feet of the formation, were identified by Dr. Stuart Weller and found to be Upper Carboniferous. The species were as follows:

Zaphrentis sp. undet.
Orbiculoidea convexa Shum.
Orbiculoidea missouriensis Shum.
Chonetes mesolobus N. and D.
Productus longispinus Sow.
Productus costatus Sow.
Productus cora D'Orb.
Spirifer cameratus Morton.
Spirifer rockymontanus Marcou.
Squamularia perplexa McCh.
Seminula argentea Shep.
Acanthopecten carboniferus Stev.
Astartella concentrica McCh.
Nucula ventricosa H.
Lida bellistriata Stev.
Pelecypod (genera and sp. undet.).
Bellerophon percarinatus Con.
Euphemus carbonarius Cox.
Patellostium montfortianum N. and P..
Bellerophon sp. undet.
Rotella verrucelifera White.
Soleniscus brevis White.
Soleniscus sp. undet.
Sphærodoma texana Shum.
Sphærodoma sp. undet.
Trachydomia wheeleri Swall. var.
Naticopsis altonensis McCh.
Naticopsis altonensis var. gigantea M. and W.
Pleurotomaria perizomata White.
Pleurotomaria (several species undet.).
Murchisonia copei White.
Orthoceras sp. undet.
Syringopora sp.
Campophyllum torquium Owen.
Straparollus catilloides Con.

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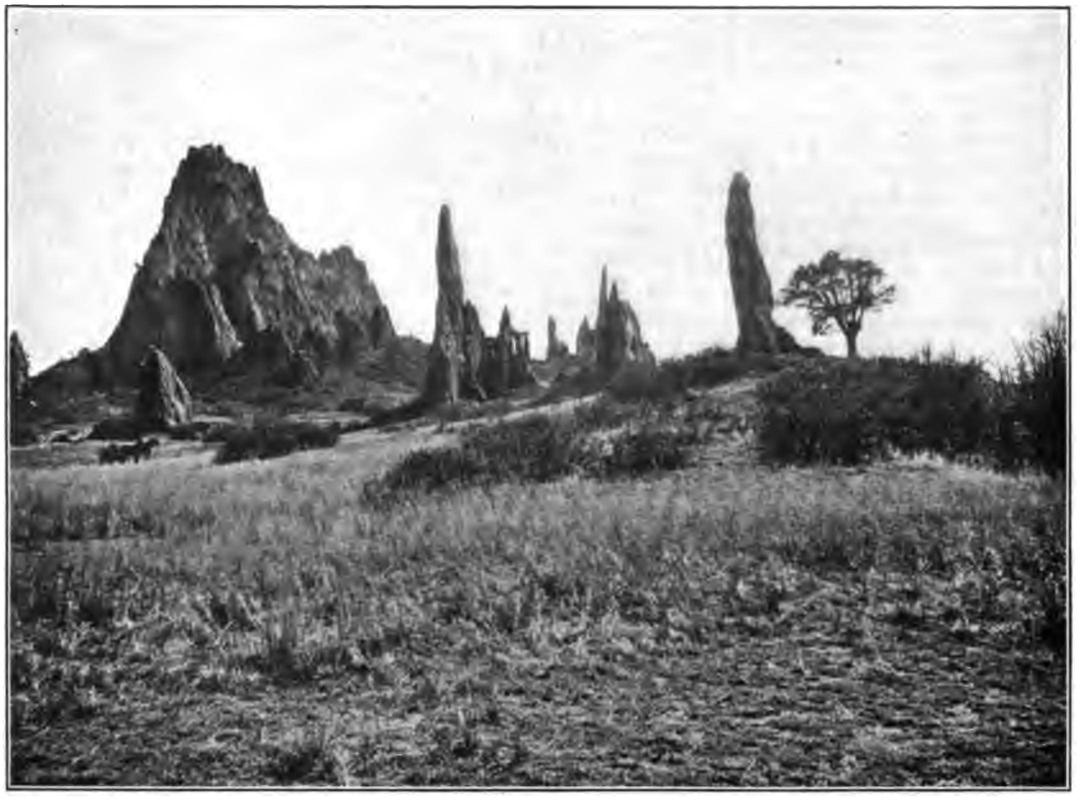
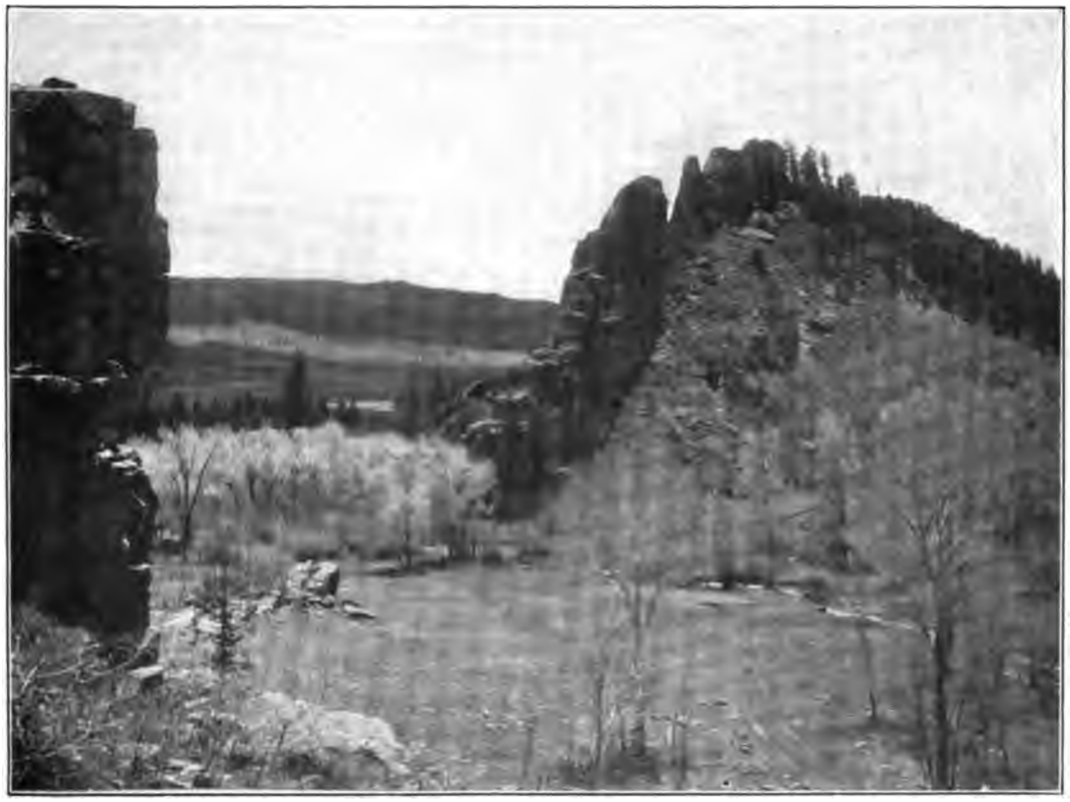
[a] Carboniferous of Sangre de Cristo Range, Colorado: Jour. Geol., vol. 10, pp. 393-396.



*A.* VERTICAL LOWER "RED BEDS," GARDEN OF THE GODS, COLORADO.

The harder portions rise in pinnacled forms.



*B.* THE STONEWALL ON PURGATORY RIVER 30 MILES WEST OF TRINIDAD, COLO.

Looking southeast across valley of Benton and Pierre shale to ridge of overlying sandstones.

Other fossils, found in loose fragments, were as follows:

Derbya crassa M. and H.
Hustedia mormoni Marcou.
Allorisma subcuneatum M. and H.
Schizodus wheeleri Swall.
Bellerophon (large sp. undet.).
Temnocheilus winslowi M. and W.
Phillipsia sp.
Large fish spine.

The following section is given by Mr. Lee:

*Section at the crest of the Culebra Range, between Middle Fork and North Fork of Purgatory River.*

| | Feet. |
|---|---|
| Hard quartzitic conglomerate | 10 |
| Dark shale | 5 |
| Limestone, fossiliferous | 2 |
| Red sandstone, with bands of red shale and irregular masses of limestone | 12 |
| Greenish argillaceous sandstone | 4 |
| Pink sandstone, argillaceous above, conglomeratic below | 18 |
| Fossiliferous limestone | 4 |
| Deep-red sandstone, conglomeratic at the base, shaly near the top | 10 |
| Limestone, arenaceous near the base | 20 |
| Massive, light-colored grit, coarse and conglomeratic | 13 |
| Banded sandstone and limestone intimately commingled; the limestone is often in more or less rounded masses; irregular beds of gravel occur in places | 6 |
| Nodular limestone | 3 |
| Massive limestone | 8 |
| Shale with limestone nodules | 3 |
| Massive limestone | 23 |
| Coarse sandstone, conglomeratic in the lower half | 20 |
| Massive grit (local unconformity) | 8 |
| Calcareous shale, passing to black shale, with limestone nodules near the top | 10 |
| Fossiliferous limestone with sandstone layers; cup corals abundant | 15 |
| Massive limestone | 6 |
| Shale | 8 |
| Coarse grit | 2 |
| Sandstone with large nodules and irregular masses of limestone | 10 |
| Shale with bands of sandstone and limestone | 25 |
| Banded limestone | 4–12 |
| Soft black shale, fossiliferous | 28 |
| Coarse grit | 9 |
| Black shale | 6 |
| Coarse grit, conglomeratic in places | 2–20 |
| Dark shale, with limestone nodules and thin seams of sandstone; runs to massive limestone in places; becomes red and arenaceous near the base | 45 |
| Coarse grit | 7 |
| Dark-red shale, with nodules and irregular masses of limestone | 10 |
| Limestone | 4 |
| Red to black micaceous shale, with bands of sandstone near the base, and limestone nodules near the top. | 12 |
| Coarse grit | 10 |
| Red grit and conglomerate | (?) |
| Crystalline rocks of the mountains. | |

A small collection of fossils was also obtained from the western slope of Veta Pass, 5 miles above Placer, in a succession consisting of sandstones, limestones, shales, and conglomerates similar to those above described. The following Upper Carboniferous forms were found at this locality:

Zaphrentis sp.
Orbiculoidea sp.
Derbya crassa M. and H.
Chonetes granulifera Owen.
Chonetes mesolobus N. and P.
Productus nebrascensis Owen.
Productus costatus Sow.
Spirifer cameratus Morton.
Squamularia perplexa McCh.
Seminula argentea Shep.
Hustedia mormoni Marcou.
Aviculopecten occidentalis.
Astartella concentrica McCh.
Schizodus wheeleri, Swall.
Bellerophon percarinatus Con.
Bellerophon inspeciosus White?
Soleniscus sp.
Conularia? sp.
Orthoceras sp.

The Millsap and underlying limestones were not found by Mr. Lee in the Culebra Range, although possibly there may be small outliers of them in portions of the range which he did not visit. The strata overlying the section given above consist of several thousand feet of red and gray sandstones, mostly coarse, extending to the base of the Morrison and representing the Fountain formation.

In the canyon of Cuchara River, near the north line of Huerfano County, the upper portion of the "Red Beds," here termed the Badito formation by R. C. Hills,[a] is exposed. At Red Rocks, in the canyon of Purgatory River, in the northern portion of Las Animas County, there are extensive exposures of the "Red Beds" and an overlying bed of gypsum which appears to belong with them. Several hundred feet are exposed, consisting at the top, under the gypsum, of a coarse, conglomeratic, massive, red sandstone, which merges downward into more regularly stratified red sandstones, with occasional layers of sandy red shales. In the uppermost sandstone the writer found a small bone fragment, apparently a portion of a scapula of a bolodont, which would suggest that this member of the formation is of Triassic age.

*Partial section of "Red Beds" in Plum Canyon near Purgatory River, Las Animas County, Colo.*[b]

| | Feet. |
|---|---|
| "Dakota" sandstone: | |
| Two massive sandstones, with clay between | 140 |
| Morrison formation: | |
| Variegated shales, with thin limestone layers | 85 |
| Dark shales, with irregular masses of gypsum | 15 |
| Gypsum, with streaks of clay | 1½ |
| Variegated shale, with much gypsum in masses up to a foot in diameter | 8 |
| Gypsum in layers sometimes separated by layers of clay | 25 |
| Massive gypsum | 5 |
| Red gypsiferous shales, soft and regularly bedded | 30-40 |
| Red calcareous sandstone, oolitic, cross-bedded, layers variable in thickness and character, shaly near top, grading into gypsiferous shales | 60 |
| Red sandstone, massive, cross-bedded | 175-200 |
| Red arenaceous shales | 6 |
| Red sandstone | 1 |
| Fine, red shale | 4 |
| Even-bedded red sandstone | 9 |
| Red arenaceous shale | 2 |
| Red sandstone, cross-bedded | 40 |

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[a] Hills, R. C., Description of the Walsenburg district: Geologic Atlas U. S., folio 68, U. S. Geol. Survey, 1900.
[b] Lee, W. T., Morrison formation of Colorado: Jour. Geol., vol. 9, 1901, p. 346.

| | Feet. |
|---|---|
| Loose red sandstone, alternating with shale | 15 |
| Massive red sandstone | 5 |
| Soft red sandstone containing ripple-marked hard layers | 30 |
| White, hard, argillaceous limestone, thin layers, contorted | 4 |
| Red sandstone to river bottom | 15 |

The correlation of these "Red Beds" with the Wyoming formation is reasonably certain when their character and relations are considered, and apparently the upper gypsiferous series represents the upper Wyoming. They underlie a wide area in southeastern Colorado and have been penetrated by some of the wells. The well at La Junta reached them at 605 feet and continued in them to 1,150 feet. The well at Bloom penetrated them from 400 feet to 1,162 feet without reaching their bottom. They also appear in some of the deep canyons south of the west end of Mesa de Maya, but their character in that region was not ascertained.

The "Red Beds" are exposed over an area of about 3 square miles in the Two Butte uplift on Two Butte Creek in Prowers and Baca counties. They are described by G. K. Gilbert,[a] who estimates that over 600 feet are exhibited. The lowest beds are sandstones and shales, the latter predominating somewhat. Some of the beds are orange or yellowish. These are overlain by white limestone 5 to 10 feet thick, which was found to be very like the Minnekahta limestone in thin-bedded character and general aspect in the outcrops. This limestone is overlain by brick-red shales about 150 feet thick, becoming sandy at the top and merging into a massive red sandstone over 300 feet thick, which forms prominent bluffs along the creek and caps the butte, which was uplifted by the laccolithic intrusion of the igneous rock. At one place this sandstone is parted by 40 to 50 feet of shale. Parts of the sandstone are buff, yellow, or gray, and somewhat resemble the "Dakota" sandstone, for which it has been mistaken here and elsewhere. It is, however, separated from the "Dakota" and probably represents the Exeter sandstone of Mr. Willis T. Lee, which appears to the south along Cimarron River.

## CRETACEOUS SYSTEM.

*Morrison formation.*—This formation extends along the base of the Rocky Mountains, where it outcrops frequently and presents very characteristic features. In a few localities, as along the foot of Cheyenne Mountain and south of Canyon, it is cut off by faults and for short distances it is overlapped by younger formations. It is also exposed in some of the canyons eastward, notably in the deeper ones of eastern Las Animas County. Its general character is nearly uniform throughout, consisting of light-colored massive clays, or "joint clays," with thin beds of limestone and sandstone of fresh-water origin, containing bones of saurians of the so-called "Atlantosaurus fauna." Its thickness averages less than 200 feet in most cases. It presents frequent and rapid variations in the local succession of beds, but the preponderance of "joint clays" of chalky aspect and the occurrence of maroon and purplish layers among them are characteristic features. The name Morrison was given by Eldridge, from the town of Morrison, where the formation is extensively developed. The Morrison beds lie unconformably on the Chugwater or gypsiferous "Red Beds" for many miles, and, southwest of Colorado Springs, overlap onto the "Red Beds" of the Fountain and Badito formations. In eastern Las Animas County they lie on a bed of gypsum. From the saurian remains which have been obtained so abundantly from the Morrison beds west of Denver and north of Canyon, the formation is regarded as latest Jurassic by some paleontologists and as earliest Cretaceous by others, but from its close connection with the overlying sandstone, the writer considers it preferable to class it as Cretaceous.

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[a] Gilbert, G. K., Laccoliths in southeastern Colorado: Jour. Geol., vol. 4, 1896, pp. 816-825.

The formation is well exposed a short distance north of the Gateway to the Garden of the Gods, where its thickness is 130 feet. The basal beds here lie on the thick deposit of gypsum at the top of the Chugwater formation and consist of ash-gray, massive shales with several thin limestone layers and a few streaks of shales with clay pebbles. These grade up into typical pale, greenish-gray and maroon, massive clays with a few thin layers of fine-grained, light-colored sandstone abruptly overlain by coarse-grained, buff-colored "Dakota" sandstone. At Colorado City the Morrison beds are exposed only in part in the railroad cut, the top and bottom members being covered by talus. The beds stand nearly or quite vertical. To the west are 55 feet of pale greenish-gray, sandy shale, mostly massive, with thin layers which are overlain (to the east) by a 15-foot bed of soft, pale greenish-gray sandstone. The formation is cut off by the fault south of Colorado City, but reappears in the embayment north and northeast of Canyon. In Garden Park, on Oil Creek, it has a thickness of about 350 feet, according to Cross,[a] and consists mainly of greenish, pinkish, or gray shales or marls with sandstone layers at various horizons. It usually lies on the Fountain formation, but overlaps locally onto the granite. In this region the formation has yielded large numbers of dinosaur remains.

Hatcher[b] has described the Morrison formation and its relations in the Garden Park area and given some details regarding the fossiliferous horizons. He estimated the thickness at 450 feet, placing the upper limit higher than Cross did, so as to include the highest sandstones and shales containing dinosaur remains. The bones have been obtained in largest number from a thick sandstone layer about 150 feet above the base of the formation shown in Pl. X, *B*, but some occur 30 feet below this stratum and others have been found at various horizons above, both in shale and in sandstones. Just below the main bone-bearing sandstone bed there is a layer of clay with thin limestone beds containing numerous fresh-water gasteropods, and at a somewhat lower horizon, a marly layer with abundant remains of unios. These shell fossils have been described by C. A. White, who classes them as Jurassic because they occur with supposed Jurassic dinosaurs, but states that otherwise they might be much younger, so that they throw no light on the age of the beds. The late J. B. Hatcher found an *Inoceramus* at the Garden Park locality.

Near Canyon there are excellent exposures of Morrison formation on the west slope of the "hogback." At the top are alternating sandstones and shales, 150 feet thick, lying on purple and green shales 160 feet thick, at the base of which there is a prominent layer of limestone 4 feet thick, which contains many fresh-water shells. Below this are 40 feet of pale bluish-green massive shales lying on sandstones. The

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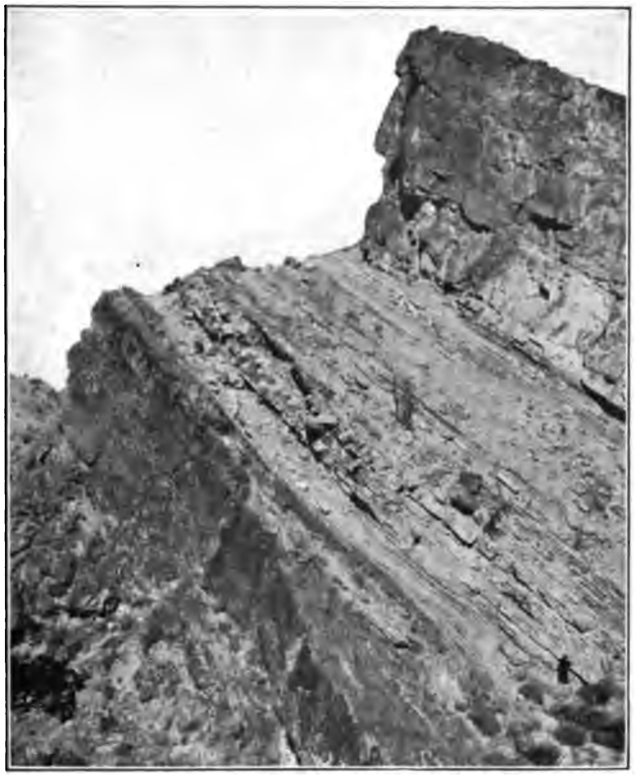
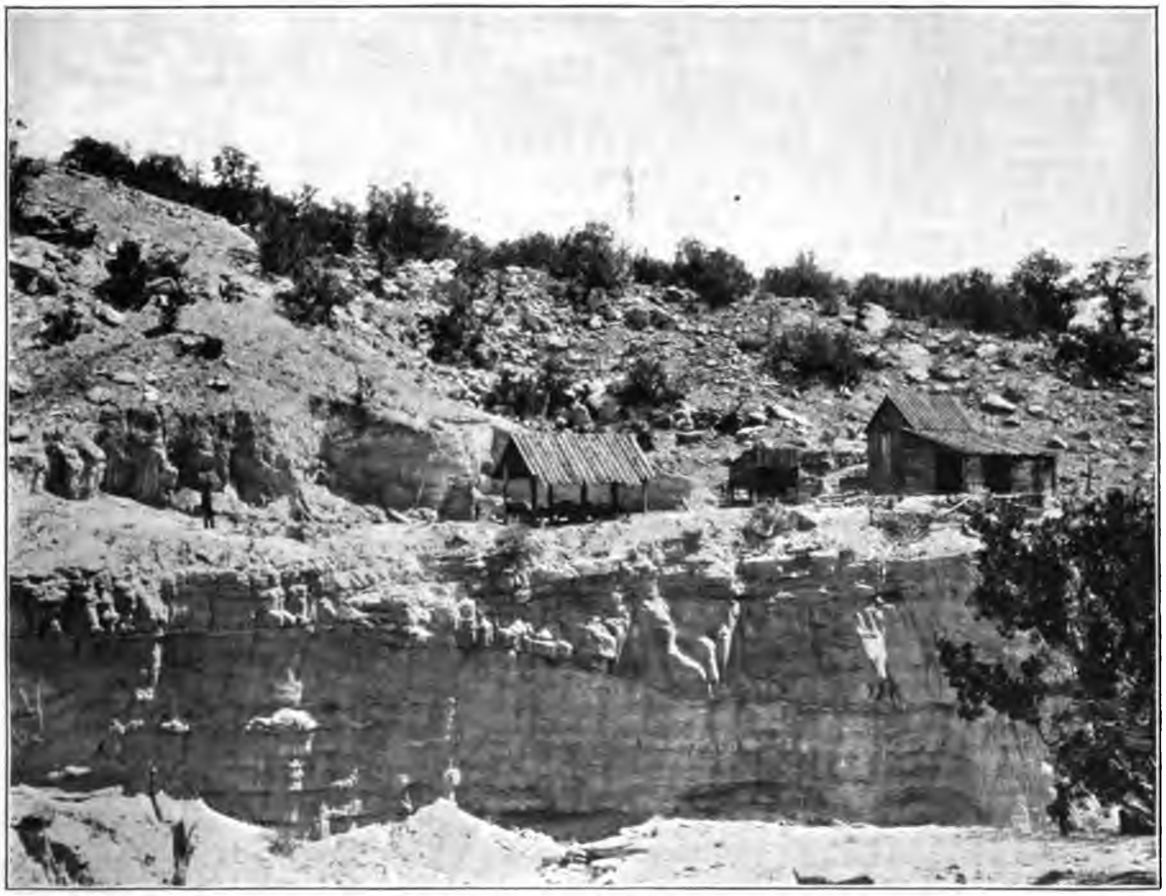
[a] Cross, Whitman, Description of the Pikes Peak district: Geologic Atlas U. S., folio 7, U. S. Geol. Survey, 1894, p. 2.

[b] Hatcher, J. B., Annals Carnegie Museum, vol. 1, 1901, pp. 327-341.



*A*. DAKOTA SANDSTONE IN HOGBACK RIDGE 2 MILES SOUTHWEST OF CANYON, COLO.

Looking north. Shows upper and lower sandstone members with intermediate shales.



*B*. BONE-BEARING SANDSTONE IN MIDDLE OF MORRISON FORMATION IN GARDEN PARK NORTH OF CANYON, COLO.

Photograph by I. C. Russell.

total thickness appears to be nearly 400 feet. Four miles south of Canyon the formation lies directly on granite, as shown in Pl. XVII, *B*, and described on page 42.

Six miles south of Canyon the Morrison beds are faulted out, or overlapped by younger strata, and do not reappear until in the vicinity of Mineral Creek south of Florence, whence they extend southward into North Creek Valley. According to Mr. G. K. Gilbert, the "Dakota" sandstone lies directly on the Fountain formation north of Beulah for several miles, but probably the Morrison beds formerly covered the region and were removed by pre-"Dakota" erosion. The Morrison beds appear south of Beulah, where, as described by Mr. Gilbert,[a] they consist chiefly of red shale with a few layers of hard, red sandstone beds about 70 feet thick. They are faulted against the gneiss and also overlap onto that rock for a portion of their course; near the contact they are paler in color, white and orange predominating, and no reds appear. The formation comes up again for 5 miles at the south end of Greenhorn Mountains, lying partly on gneiss and partly on the "Red Beds." Its thickness here, according to Hills,[b] is 270 feet, the lower portion consisting of about 60 feet of soft white sandstone, conglomeratic at base. The middle portion is a series of pinkish and greenish massive clays, and the upper beds are variegated shales and clays, alternating with bands of fine-grained limestone often containing vermilion-colored cherts. Hills states that there is considerable doubt as to the true position of the formation in the time scale, but assigns it provisionally to the Jurassic.

Mr. Willis T. Lee has made a special study of the Morrison formation in the southern Colorado region,[c] and his work has thrown much light on its distribution and components. He describes its continuation southward along the foot of the Rocky Mountains west of the Spanish Peaks into New Mexico and its existence in the deep canyons of Las Animas County, Colo., and southward. He has found that it presents its usual characteristics, regular stratigraphic position and dinosaur remains. The first exposures east of the foot of the mountains are in Cuchara and Huerfano canyons in western Huerfano and southern Pueblo counties, where Hills reports the formation as 100 feet thick and consisting of variegated shales and clays alternating with layers of fine-grained limestone. In Apishapa Canyon north of Thatcher the typical Morrison is reported by Lee, underlying the "Dakota" sandstone. There are extensive exposures in Purgatory and adjacent canyons where the "Red Beds" are uplifted. Mr. Lee gives the following section, in Plum Canyon near its mouth:

*Geologic section of Morrison formation in Plum Canyon, Las Animas County, Colo.*

| "Dakota": | Feet. |
|---|---|
| Massive sandstones | 140 |
| Morrison: | |
| Greenish clay and shale, soft and fine grained | 11 |
| Dull red clay, soft and fine grained | 12 |
| Brown to yellow shale | 10 |
| Argillaceous limestone, fine, dark laminæ | ½ |

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[a] Gilbert, G. K., Description of the Pueblo quadrangle: Geologic Atlas U. S., folio 36, U. S. Geol. Survey, 1897.

[b] Hills, R. C., Description of the Walsenburg district: Geologic Atlas U. S., folio 68, U. S. Geol. Survey, 1900.

[c] Lee, Willis T., Jour. Geol., vol. 9, pp. 343-352; vol. 10, pp. 36-58.

| Morrison—Continued. | Feet. |
|---|---|
| Buff-colored shale | 1½ |
| Argillaceous limestone, fine, dark laminæ | ½ |
| Variegated joint clay | 18 |
| Argillaceous limestone, fine grained and hard with contorted laminæ | 2 |
| Variegated shales, very soft | 30 |
| "Red Beds"?: | |
| Dark shale and gypsum on Red Beds. | |

Lee gives the following section in Red Rock Canyon, a small side canyon of Purgatory River:

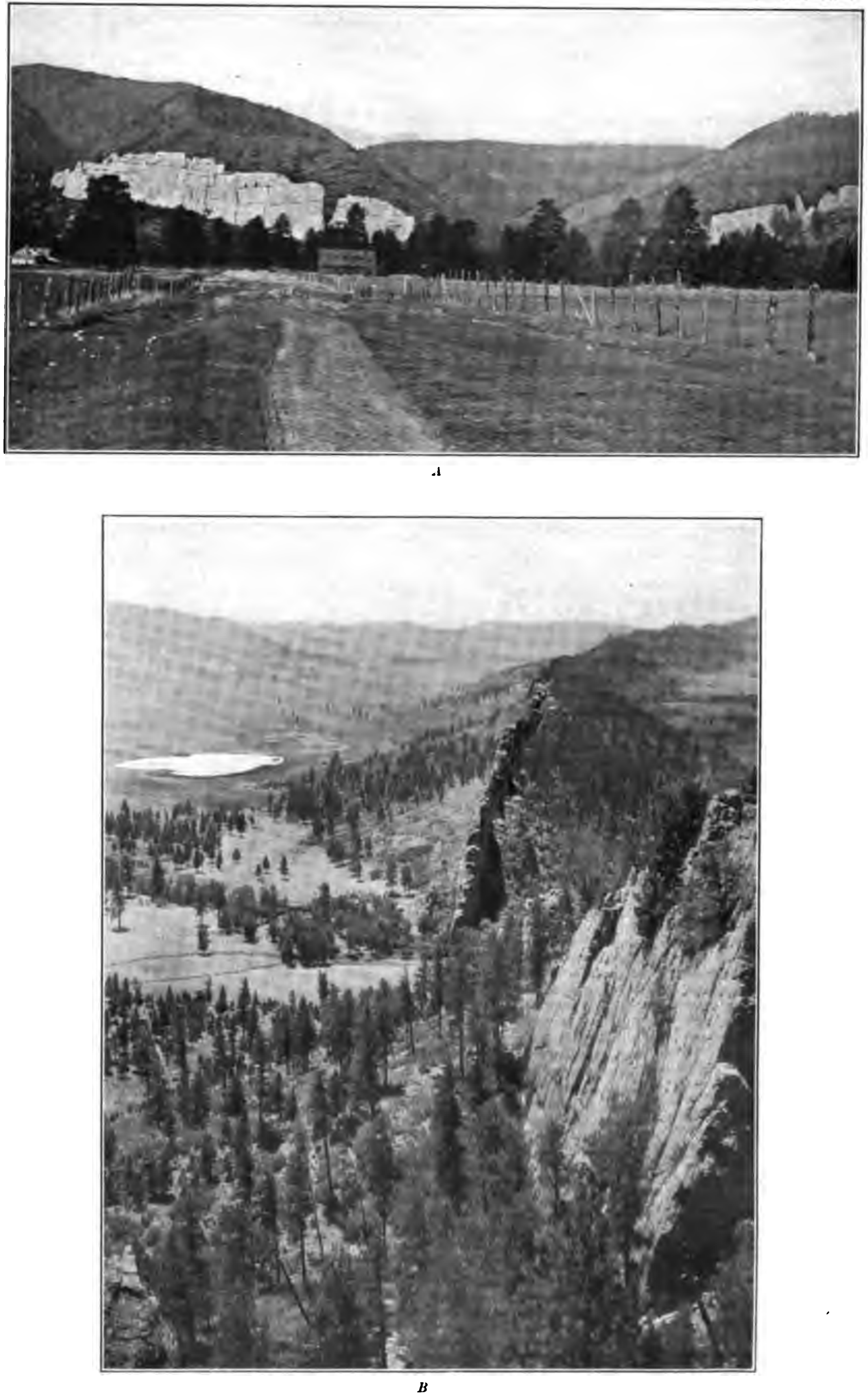
*Geologic section of Morrison beds in Red Rock Canyon, Las Animas County, Colo.*

| | Feet. |
|---|---|
| "Dakota:" | |
| Massive sandstone | |
| Morrison: | |
| Brick-red sandy shale, with bands of hard, fine-grained sandstone | 25 |
| Reddish limestone, conchoidal fracture | 3–5 |
| Soft, dark, clay shale | 30 |
| Light-brown clay shale | 11 |
| Argillaceous limestone | ½ |
| Brown shale | 7 |
| Concretionary limestone | 1 |
| Variegated joint clay | 7 |
| Yellow paper shale | 3 |
| Argillaceous limestone, thin layers | ½ |
| Fine shale | 1½ |
| White limestone | 1 |
| Variegated clay shale | 15 |
| Argillaceous limestone, thin layers | ⅔ |
| Yellow shale | 4 |
| Sandstone with agate masses | 1 |
| Soft, thin-bedded sandstone | 8 |
| Soft massive sandstone | 2 |
| Paper shale | 2 |
| Soft massive sandstone | 7 |
| "Red Beds:" | |
| Gypsum and clay on red sandstone | 12–20 |

In this canyon the thickness is 132 feet; in Chaquaqua Canyon, 10 miles from the mouth of Plum Canyon, it is 175 feet(by barometer), and the predominating material is a variegated clay shale popularly termed "joint clay." Lee says:

> A subordinate amount of sandstone occurs in places, but there seems to be no particular horizon at which this is likely to be found. In Red Rocks Canyon it occurs at the base; in Plum Canyon none is found; in a side gulch east of Plum Canyon a brecciated layer occurs near the top containing angular fragments one-fourth inch in diameter; in Chaquaqua Canyon, 4 miles from the mouth of Plum Creek, a coarse, cross-bedded sandstone layer 15 feet in thickness occurs about 50 feet from the top; just across the canyon from this point, perhaps 2 miles distant and at the same horizon, about 30 feet of limestone is found in place of the sandstone. In many places the sandstones are friable and composed of nearly pure quartz. * * * The occurrence of the limestones, most of which are more or less argillaceous, is as erratic as that of the sandstones. The relative amount and position of sandstone, shale, and limestone vary locally.

Dinosaur bones were observed by Mr. Lee in the shales at nearly every horizon, but no invertebrates were found. It is reported that the formation is sharply separated from adjoining formations, but without evidence of unconformity by erosion.



THE STONEWALL ON PURGATORY RIVER WEST OF TRINIDAD, COLO.; A MONOCLINAL RIDGE OF "DAKOTA" SANDSTONE.

*A*. Looking west to Culebra Range. *B*. Looking south, showing red valley to right and valleys of Graneros and overlying shales to left.

The gypsiferous shales appear to be distinct, and are regarded as a portion of the "Red Beds." The formation extends down Purgatory River to the west line of Bent County, where it passes beneath the "Dakota" sandstone. In Muddy Creek Valley, in the southern corner of Bent County and the adjoining portion of Las Animas County, the Morrison formation is bared of "Dakota" sandstone over an area of several square miles in which the same general features are presented as in Purgatory Valley. It again appears in Longs Canyon, and the writer found it apparently exposed in the Two Butte uplift on Two Butte Creek, where it is thin, but consists of gray and purplish clays with layers of light-colored sandstones and limestones overlying buff and red sandstones at the top of the "Red Beds." In a paper presented to the Geological Society of America, in December, 1902, Mr. Willis T. Lee announced that he had traced the formation eastward down the Cimarron Valley into Oklahoma.

*Comanche series.*—This series was first discovered[a] in Colorado on Two Butte Creek, 5 miles east of Two Butte, and during the summer of 1905 Mr. T. W. Stanton and Mr. Willis T. Lee found Comanche fossils in the fire clay lying between the two sandstones of the "Dakota" in Purgatory Canyon south of La Junta, while later Mr. Stanton found them in the same position west of Canyon. This important discovery indicates a wide extension of the formation to and along the Rocky Mountain Front Range, constituting the middle and lower portions of the "Dakota" formation. At the Two Butte Creek locality the creek crosses a low anticline in which the upper member of the "Dakota" sandstone is seen to be underlain by 20 feet or more of sandy shales containing numerous *Gryphæa corrugata* Say, a fossil characteristic of the upper part of the Comanche series. The locality is just above Mechling's ranch, in bluffs along the south bank of the creek. Doubtless the Comanche beds underlie the greater part of Baca County, for they have been discovered by Mr. Willis T. Lee along the Cimarron near the New Mexico–Oklahoma line. Possibly they are exposed along Bear and Horse creeks, but these streams have not been especially examined for outcrops of beds underlying the top "Dakota" sandstone.

*"Dakota" sandstone.*—Under this heading will be described the entire sandstone succession overlying the Morrison formation, for this always has been known as the "Dakota" sandstone or "Dakota" formation. It generally consists of two bodies of sandstone, each a hundred feet or more in thickness, separated by a deposit of clay or shale from 10 to 15 feet thick. This clay in the Golden region and the top sandstone at various localities have yielded abundant plant remains of the Dakota flora (Upper Cretaceous). The tripartite succession strongly suggests the Dakota sandstone, Fuson clay, and Lakota sandstone of the Black Hills, and the Lower Cretaceous age of the two latter, at least in southeastern Colorado, is proved by the occurrence of Comanche fossils in the fire-clay member, as described in a preceding paragraph.

The "Dakota" sandstone is remarkably uniform in character throughout eastern Colorado. The sandstones are mostly hard and massive, giving rise to a well-marked hogback range along the foothills (Pls. V and IX, *B*) and plateaus, with steep-walled canyons in the southeastern part of the State (Pl. IV, *B*). The predominating color is light buff, but some portions are light gray or white, and darker tints are not infrequent, especially in the upper beds. Cross-bedding is almost general and conglomeratic streaks are frequent, especially at or near the base of the lower sandstone. The contact with Morrison beds is abrupt and often presents evidence of slight unconformity by erosion. There is often a rapid change to Benton deposits, but in most areas there are a few feet of transition beds consisting of an alternation of shales with thin-bedded brown sandstones. The lower sandstone member is thicker than the upper, often somewhat softer, and it contains shale partings at some localities. The middle shale member appears to be present throughout, but generally it is covered by talus. It is well shown in Pl. X, *A*. In the Garden of the Gods region Doctor Peale reports a thickness of 257 feet, consisting of 200 feet of massive sandstones above, underlain by a finer-grained sandstone, in part yellow, containing fragments of *Lingula* and a lignitic layer with vegetal fragments. The writer's measurement in vertical beds near the Gateway gave considerably less thickness, and the formation was found to consist of two massive beds of sandstone, apparently with a thin series of shales between. The great fault cuts off the formation southwest of Colorado Springs, but it appears again in the region of Canyon, where Cross describes it as having a thickness of 300 feet and as consisting mainly of pure white or gray sandstone, usually friable, of uniform texture, with a thin basal conglomerate. Dark shale layers are reported midway in the formation in which, in the summer of 1905, T. W. Stanton found Comanche fossils. Fossil leaves are said to occur in thin layers at various horizons.

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[a] Decsribed by N. H. Darton, in Science, vol. 22, p. 120, 1905.

"Dakota" sandstone is prominent at the foot of Wet Mountains southwest of Pueblo, as described by Mr. Gilbert.[a] Its greatest measured thickness is 650 feet, near Beulah, where it consists almost entirely of sandstone; elsewhere in the area it contains beds of shale and is 300 to 350 feet thick. The basal portion usually is conglomeratic, sharply separated from the Morrison clays and the Fountain formation, which it overlaps locally. At the top there is a transition into the Benton (Graneros) shales, through an alternation of shale and thin-bedded, brown sandstones.

In the northern portion of Huerfano County and along the foot of Greenhorn Mountain the formation is described by Hills as consisting of 350 feet or more of sandstone, of which the lower two-thirds consists generally of a yellowish-gray rock of coarse, porous texture, with some layers of fine conglomerate, commonly cross-bedded. This lower member is separated from the upper one by gray shales 8 to 10 feet in thickness. The upper sandstones aggregate 100 to 150 feet in thickness, are light gray, and of fresh, fine-grained, close texture, regularly bedded. The formation lies in part on the Morrison, but in places along the mountain front overlaps the granites and schists. In the canyons of Cuchara and Huerfano rivers it lies nearly level and presents steep canyon walls surmounting slopes of Morrison clay. The "Dakota" sandstone is a prominent feature in the foothills extending between Spanish Peaks and the Sangre de Cristo Range, appearing for many miles as a vertical "stone wall" rising high above the adjoining softer beds.

In the extensive exposures of "Dakota" sandstone in the eastern half of Las Animas County is presented a regular succession of the two massive sandstone layers with their intervening shales or fire clay containing Comanche fossils. Referring

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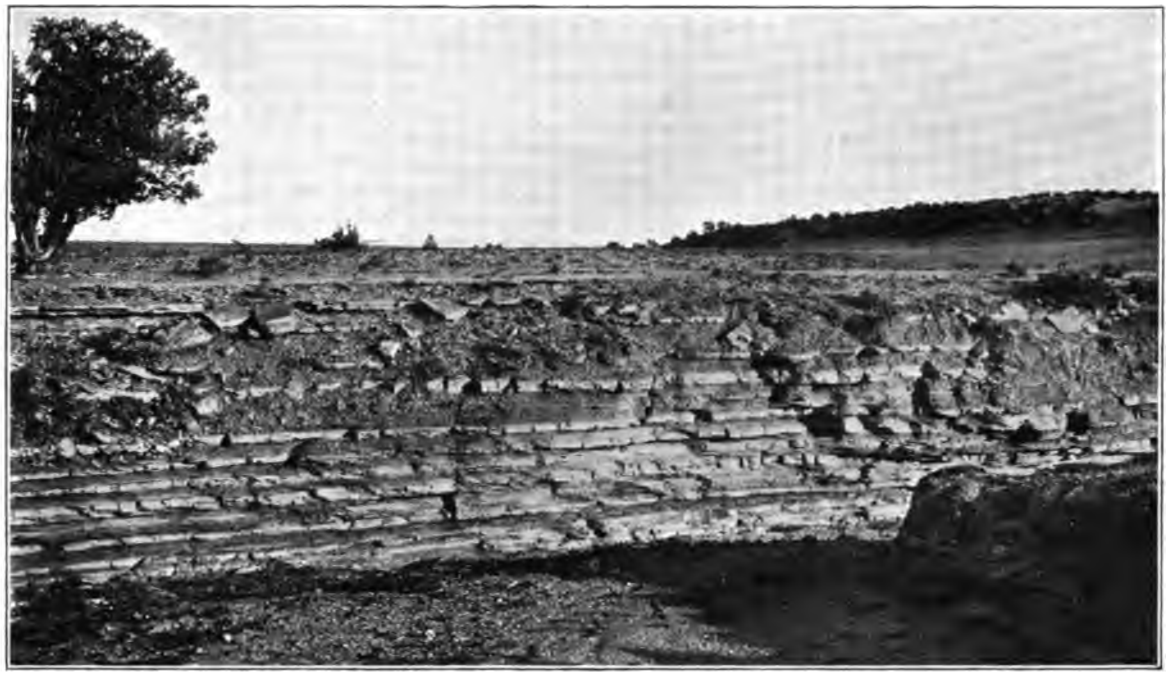
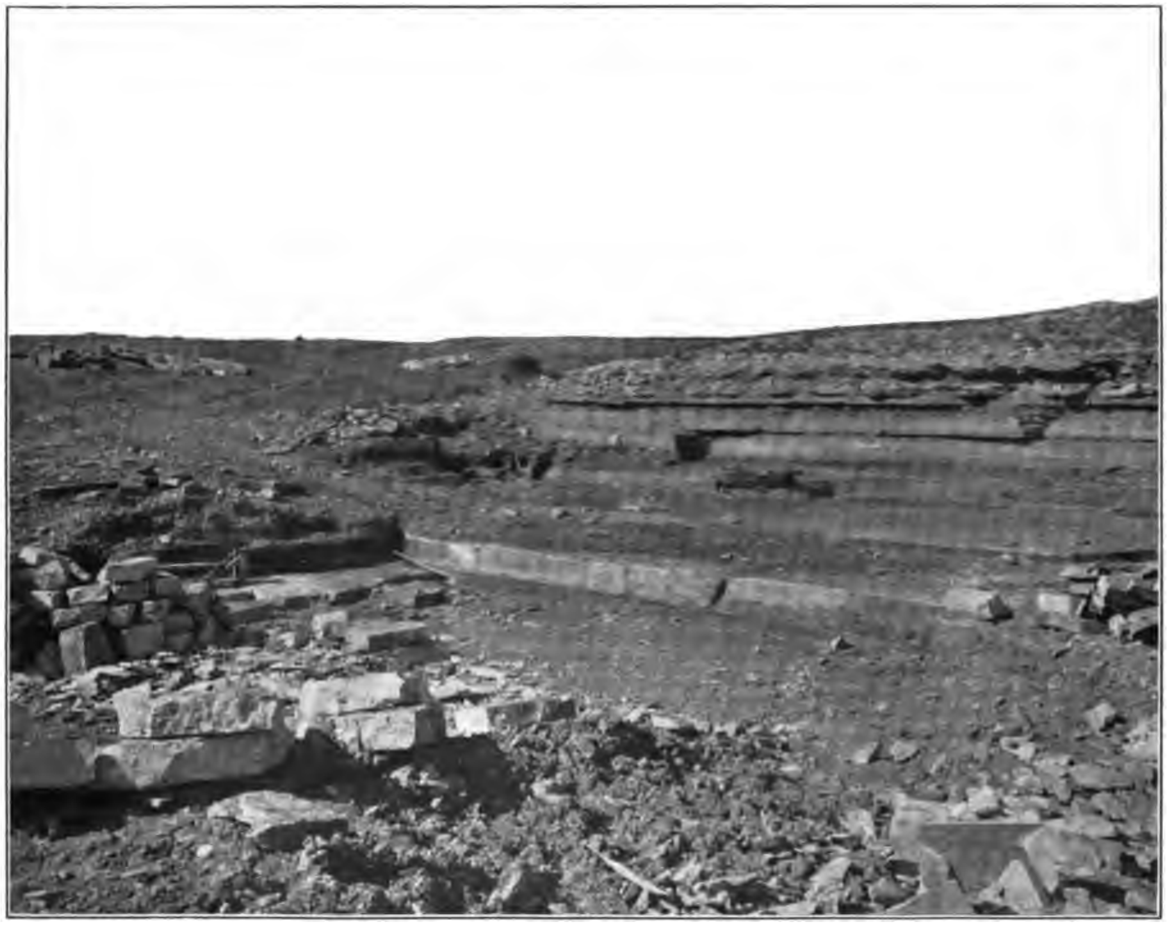
[a] Gilbert, G. K., Description of the Pueblo quadrangle: Geologic Atlas U. S., folio 36, U. S. Geol. Survey, 1897, p. 6.



*A.* GREENHORN LIMESTONE NEAR THATCHER, COLO.

Typical view showing limestone with interbedded black shales. Base of this formation is about 200 feet above water-bearing Dakota sandstone.



*B.* TIMPAS LIMESTONE IN QUARRY SOUTHEAST OF LA JUNTA, COLO.

Shows thickness of beds and intercalations of shale.

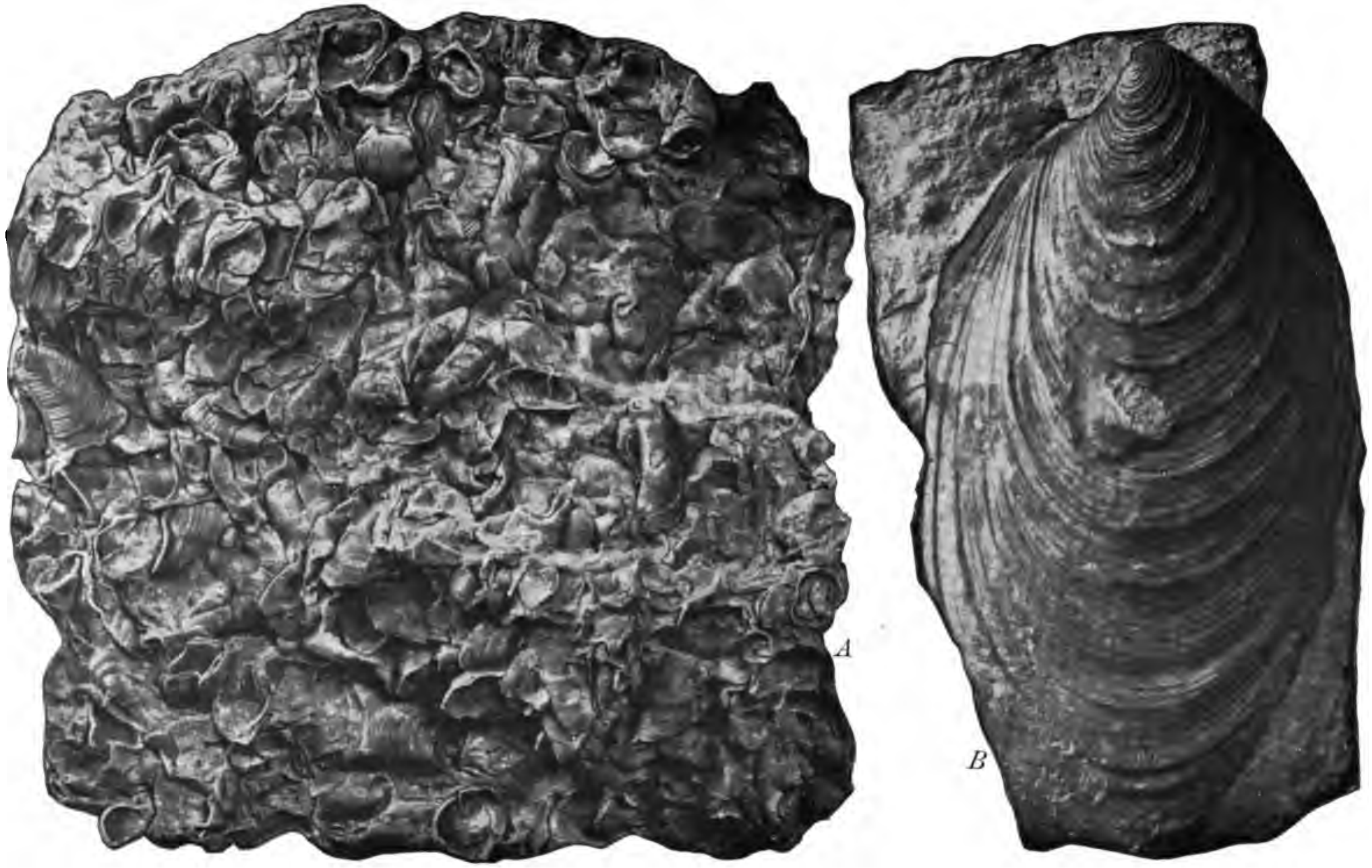
to the formation in Purgatory Canyon, near longitude 104°, Hills states that the thickness is about 375 feet, and that the lower two-thirds consists of massive, mostly cross-bedded sandstones, with a few shale partings between the beds and more or less fine conglomerate. This basal member is overlain by a layer of fire clay, the position of which is marked by a narrow shelf due to the projection of the underlying sandstone. The upper sandstone is grayish white, thinner bedded, with more numerous shale partings and generally finer grain and more compact than the lower, more porous sandstone. These features prevail over the wide area of "Dakota" outcrop in southeastern Colorado, in Baca, Prowers, and Bent counties, but with many variations of thickness and local details of stratigraphy. In the vicinity of the Two Butte uplift the sandstone has been extensively eroded over an area about a mile square. The buttes are capped by a thick, massive sandstone (Exeter?), which is the upper member of the "Red Beds" and is separated from the "Dakota" sandstone by supposed Morrison shales and limestones.

*Graneros shale.*—This shale, which is the basal member of the Benton group, underlies a large portion of eastern Colorado. It outcrops in a narrow zone along the foothills of the Rocky Mountains and in broader areas on the flanks of the anticlines in Pueblo, Huerfano, and Las Animas counties, and along the Arkansas Valley east of La Junta. Its thickness generally averages 200 feet, and it appears to be perfectly conformable to the adjoining formations. Usually there are a few feet of transition beds to the "Dakota" sandstone at its base and to the overlying Greenhorn limestone. The shale is mostly hard and fissile; its color is bluish gray, darkest in the middle and slightly lighter in the upper and lower beds. Thin beds of white clay occur locally. In the region south of Pueblo the formation contains a layer of limy sandstone 1 to 2 inches thick about 50 feet below the top of the formation. It contains fossil shells of several species. Concretions of carbonate of lime occur at various levels in most localities, especially 20 to 30 feet above the base of the formation. In some districts this horizon of concretions changes into a layer of dark-gray limestone, 8 inches to a foot in thickness, which weathers to a bright-orange color. In general the formation appears in gentle slopes of gray clay, with occasional concretions, and in some recently cut banks the shaly character of the less weathered material is apparent. In most of the Arkansas Valley region the thickness varies only from 200 to 210 feet, but north of Canyon it is between 325 and 350 feet, and 3 miles south of that city it is 250 feet. The limestone layer occurring 30 feet above the base of the formation is most conspicuous in the region east and northeast of Trinidad, where its thickness is 1 to 2 feet. It is hard and of concretionary structure. It weathers to a bright-orange color, so that it is a conspicuous feature.

*Greenhorn limestone.*—This medial formation of the Benton group outcrops along the margin of the Graneros shale area above described. Its thickness varies from 30 to 50 feet. It consists of beds of pale bluish-gray, fine-grained, compact limestone, mostly 3 to 10 inches thick, separated by dark-gray shales 4 to 18 inches thick. (Pl. XII, *A*.) These intermediate shale beds are usually thicker where the formation is thickest. The limestone has a strong tendency to split with vertical cleavage into small slabs one-fourth inch to 2 inches in thickness, which form a conspicuous feature on the slopes. At most localities the formation grades into the adjoining formations through a few inches of passage beds. A few thin beds of white clay have been reported as occurring in the formation at points in the vicinity of Pueblo. Most of the limestone beds contain an abundance of a highly characteristic fossil, *Inoceramus labiatus*. This form is represented by casts and impressions often closely packed together in some of the layers. The appearance of this fossil is shown in Pl. XIII, *B*. It is not known to occur in any of the formations. In the shales between the limestone layers a somewhat similar fossil occurs, often in considerable abundance. In most districts the ledges of Greenhorn limestone give rise to low mesas or shelves in the slopes and often bear a scattered growth of cedars and piñons. The thickest development of the formation is 2 miles north of the city of Canyon, where it is 60 feet thick, while in Webster Park it is not over 10 feet thick.

*Carlile formation.*—The Carlile formation, which consists mainly of shale, outcrops along the foothills of the Rocky Mountains in the anticlinal area west, south, and southeast of Pueblo, along the north side of the Purgatory Valley northeast of Alfalfa, and down the north side of the Arkansas Valley below La Junta. Small areas occur on divides southeast and southwest of Lamar. The formation consists mainly of shale of dark-gray color, averaging 200 feet thick. The middle beds are usually the darkest, some of them being black. At the top there is a bed of sandstone varying in thickness from a few inches to 20 feet, the amount increasing to the west. In the same direction, also, the upper fourth of the formation becomes somewhat more sandy and occasional thin beds of sandstone appear. In these sandy beds occur numerous oval and globular concretions which often attain a diameter of 1 foot to 5 or 6 feet. Most of them are traversed by cracks filled with wine-colored calcite. The top sandstone averages 10 to 20 feet in thickness west of longitude 104° and attains a maximum of 30 feet at Greenwood on Hardscrabble Creek, and near Chandler, south of Canyon. Near La Junta it is 3 feet thick, having the relations shown in Pl. XV, *B*. Usually it is soft, somewhat mixed with sandy shale and of yellowish color. The fossil known as *Pugnellus* occurs abundantly in the formation in the southwestern portion of the area. At the top of the Carlile formation in the southern and central portions of the region to which this report relates there is a purplish limestone 6 inches to 2 feet in thickness, in which the large coiled shell *Prionocyclus wyomingensis* is of frequent occurrence. From 50 to 75 feet above the base of the formation in most districts, especially to the east, a thin limy layer containing fossils is often found.

*Timpas limestone.*—The Timpas limestone is the lower member of the Niobrara group. Its thickness varies from 175 to 200 feet, and it consists of a basal limestone with overlying alternations of limestone and shale, all of light color. It is a conspicuous formation in eastern Colorado, underlying all of the region east of the Rocky Mountains, except on the anticlines south and southeast of Pueblo and along the Arkansas Valley east of La Junta. In the region east of Colorado Springs it lies deeply buried beneath younger formations, but it appears extensively in the Arkansas Valley and in a broad belt extending across the eastern parts of Huerfano and Las Animas counties. A small outlier appears on the high ridge 25 miles southwest of Lamar, and there is continuous outcrop of the formation along the north side of the Arkansas Valley east of Rocky Ford. At the base of the Timpas there is a lime-



CHARACTERISTIC FOSSILS OF NIOBRARA AND GREENHORN LIMESTONES.

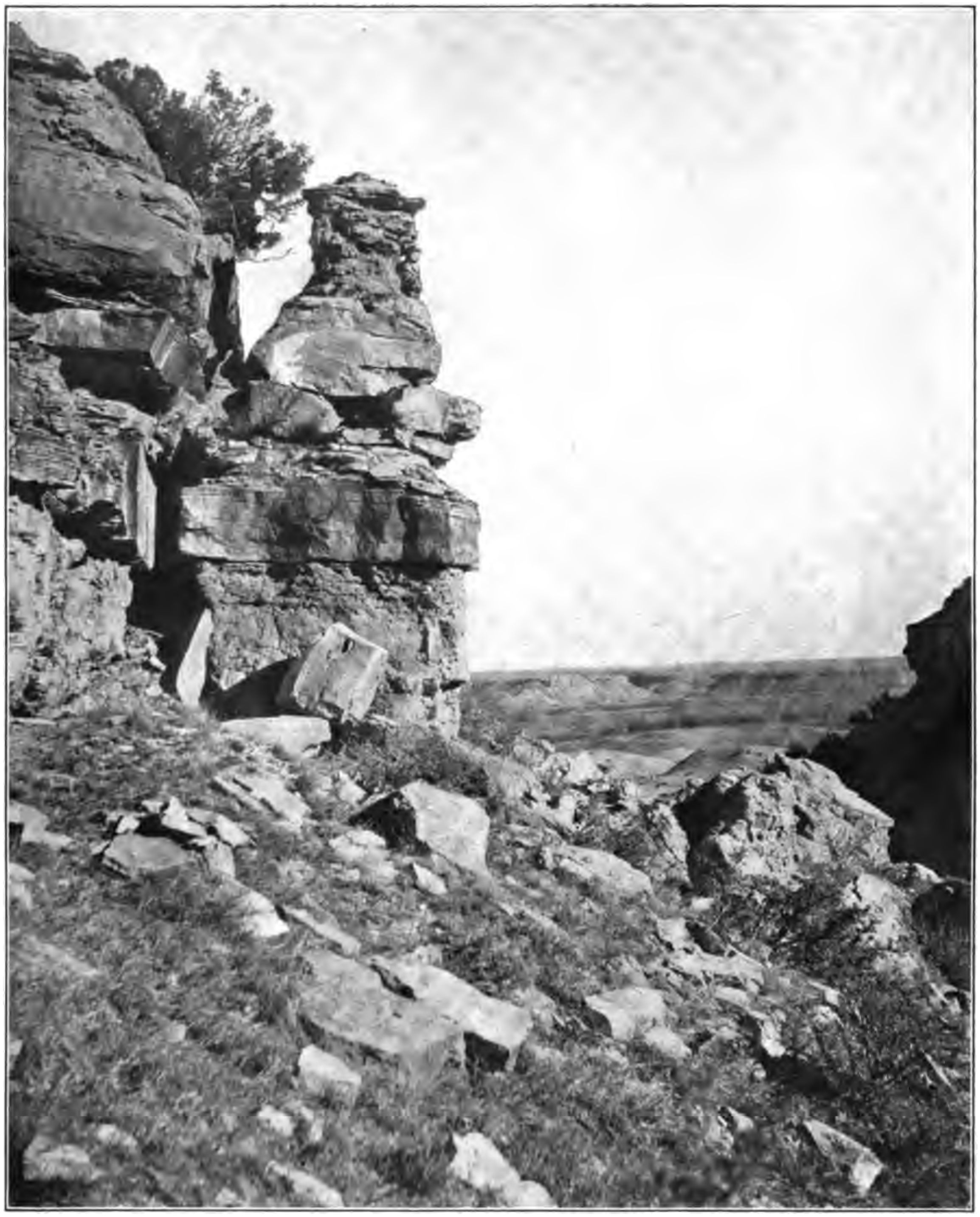
*A*, Ostrea congesta; *B*, Inoceramus labiatus.

stone series about 50 feet thick, which usually outcrops in a ledge or rocky slope of considerable prominence. (Pl. XII, *B*, and XV, *B*.) It consists of beds in layers, mostly 6 inches to a foot in thickness, separated by 1 to 2 inches of light-gray, calcareous, limy shale. The limestone is white, or of a very light-gray color, becoming creamy white on weathering. It is compact, fine grained, and has an easy conchoidal fracture rudely parallel to the bedding. Owing to the latter property it usually weathers into flat flakes 2 or 3 inches long, differing in this respect from the Greenhorn limestone, which cleaves into vertical flakes. The lighter color is also a distinguishing feature. In the eastern portion of the area the rock has a more chalky texture. In the lower beds small nodules of a form of iron sulphide known as marcasite occur, which usually weather out as limonite. These are of dark-brown color and spherical or cylindrical in shape, usually one-fourth to three-fourths inch in diameter. These often accumulate in considerable number on the weathered surfaces. The limestone contains a characteristic fossil known as *Inoceramus deformis*, which occurs scattered at intervals through the beds. The shell is thick, has a roughly corrugated surface, and its larger valve has a shallow cup shape. Occasionally shells of a small oyster, *Ostrea congesta*, occur upon it, but these are also sometimes found separately. Much of the limestone consists of minute organisms known as foraminifera, which are plainly visible when thin slices of the rock are examined under the microscope. Above the basal limestone are about 100 to 150 feet of calcareous shale of light-gray color, containing occasional thin beds of grayish-white limestone. Toward the top of this member there are two or three thicker, persistent layers of limestone, 12 to 18 inches thick, separated by a few feet of shales and marking the top of the formation.

Fossils occur in the upper shales, consisting mostly of a very broad, flat *Inoceramus*, usually covered by *Ostrea congesta*. In the Pueblo region the lowest stratum of the limestone is an impure sandy limestone 1 to 2 feet thick, of dark-gray color, which weathers to a yellowish-brown tint. It contains teeth of sharks and other fishes and numerous dark pebbles half an inch in diameter.

*Apishapa formation.*—In southern Colorado the upper part of the Niobrara group has been separated as the Apishapa formation. It consists mainly of shale and calcareous shale, with a few layers of cream-colored limestones at the top. The thickness varies from 400 to 700 feet, but averages about 450 feet in the greater part of the region. Many of the shales vary in color from light gray to dark gray and are sandy, with intercalations at intervals of dull-gray to cream-colored limy shales and impure limestones. The most persistent lime deposits are an alternation of yellow limestones and light bluish-gray limy shales 10 to 20 feet thick, marking the top of the formation. The lowest beds are mostly dark fissile shale about 50 feet thick. These are followed by about 100 feet of soft, papery shales of dark-gray color. The middle portion of the formation is decidedly sandy, while the upper 100 feet of the formation, especially in the region between Pueblo and La Junta, consists of dark bluish-gray fissile shale, containing two and sometimes three horizons of cream-colored limestone. At various horizons in the formation, especially toward the top and eastern part of the district, calcareous concretions occur. They are usually of considerable size and of lens shape. In some areas they give place to thin layers of concretionary limestone, which are of sufficient hardness to form ledges or low hills in the smooth slopes of the adjoining beds. In the region north and east of Trinidad the Apishapa formation consists of about 40 feet of dark-gray to blue-gray shales at the base, followed by 90 feet of soft, papery shales, which grade upward through the blue, sandy shales into alternations of limy and sandy shales. Near the middle of the formation these sandy shales become coarser and flag-like, constituting about one-third of the formation. This member is usually somewhat bituminous. The upper 100 feet resembles the basal portion, but includes two and in places three thin layers of limestone and lens-shaped concretions of impure limestone. The fossil remains consist of fish scales, which are generally abundant in the shales and sometimes in the coarser flag-like layers. Crustacean tracks also sometimes occur. Fish scales from half an inch to an inch in diameter are usually abundant. Portions of the Apishapa beds weather to a bright-straw color, which is a conspicuous feature in its outcrops. *Ostrea congesta* is a characteristic fossil, usually closely packed in masses a foot or more in diameter, and is from half an inch to an inch thick (Pl. XIII, *A*).

*Pierre shale.*—The calcareous deposits of the Niobrara group are succeeded by a great thickness of the dark-gray Pierre shales. These underlie the deep structural basin extending from east of Colorado Springs south to the Arkansas Valley between Pueblo and Manzanola, the Florence basin, and the deep syncline in central Huerfano and Las Animas counties. Their thickness is over 3,000 feet in the district east of Colorado Springs and about Florence, but the amount diminishes to the south and is not more than 1,600 feet in the vicinity of Trinidad. In the vicinity of Arkansas River below Pueblo several distinct zones have been recognized in the formation. The lower beds for a thickness of 400 to 500 feet are of medium-gray color and yield no fossils. They contain much selenite in minute flakes. Next above is a zone of similar-colored shales containing less selenite and characterized by a great abundance of oval concretions, usually 4 to 8 inches thick and 1 to 2 feet long. These are fine grained, dark gray in color, and consist of carbonate of lime and carbonate of iron. On weathering these concretions break into small angular fragments of dark rust-brown color, which are often so abundant on the slopes as to give them a reddish color. On this account the beds have been called the "Rusty zone." Their thickness is about 600 feet. Beginning in the top of this zone and extending upward 100 to 200 feet is a noticeable abundance of fossils known as *Baculites compressus.* Their form is that of a flattened cylinder, slightly tapering, and sometimes showing the remains of the shell. They are often a foot in length and 2 inches in diameter, but most of them are smaller. This form occurs at other horizons, but is most abundant here. Next above the "Rusty zone" are shales of somewhat lighter color, in the upper portion of which occur masses of limestone, often constituting small conical hills, or "tepee buttes," as they have been termed (Pl. XV, *A*). These limestone masses consist of coarse-textured, gray, fossiliferous rock, often rudely cylindrical in form and standing vertical within the shale mass. Ordinarily they are 5 to 30 feet in diameter and of considerably greater length. As they offer more resistance to erosion than most of the adjoining shales, the core and the fragments of rock derived from it often rise in conical hills 25 to 50 feet above the surrounding surface. Fossils occur in the limestone in considerable variety, but the most abundant species is a small oval bivalve known as *Lucina occidentalis.* The zone of the tepee



VIEW ALONG ARKANSAS RIVER WEST OF PUEBLO. BASAL TIMPAS LIMESTONE ON CARLILE SANDSTONE.

buttes is apparently several hundred feet thick, but its precise stratigraphic limits could not be determined. In this zone there also occur smaller lens-shaped limestone, concretions, 6 to 12 inches thick and 1 to 3 feet in diameter, containing large numbers of beautifully preserved fossils of various kinds. In many cases the original shell is preserved, retaining its original pearly luster. Above the tepee zone the shales become darker, are less fossiliferous, and contain fewer concretions. The amount of selenite in small crystals increases considerably. The top of the formation is somewhat indefinite, the shales gradually giving place to sandy beds. In the region between Walsenburg and Trinidad the basal and upper zones weather to a yellowish-green color; the middle zone is dark gray and lead gray, occasionally almost black. The latter zone contains an abundance of lime and iron concretions, which break up readily and impart a rusty tint to the surface.

An analysis of a typical sample of tepee rock, made by Dr. W. F. Hillebrand,[a] of the United States Geological Survey, is as follows:

*Analysis of limestone in tepee core.*

| | |
|---|---|
| Silica ($SiO_2$) | 7.46 |
| Titanium dioxide ($TiO_2$)<br>Alumina ($Al_2O_3$) | 1.78 |
| Iron sesquioxide ($Fe_2O_3$) | .94 |
| Lime (CaO) | 46.98 |
| Magnesia (MgO) | 2.36 |
| Potash ($K_2O$)<br>Soda ($Na_2O$) | .37 |
| Phosphoric oxide ($P_2O_5$) | undet. |
| Carbon dioxide ($CO_2$) | 39.25 |
| Water loss at 100° C. | .16 |
| Water loss above 100° C.<br>Organic material | .70 |
| | 100.00 |

The limestone constituting these tepee cores bears a marine fauna. *Lucina occidentalis* is the most abundant molluscan species, forming a leading constituent of the rock. *Inoceramus* is rather common and cephalopods occur in considerable variety. Foraminiferal forms frequently disclose themselves under the microscope. The occurrence of fossil wood has also been reported from some of the cores. The following is a list of the molluscan species determined by T. W. Stanton, from specimens collected by Mr. Gilbert:

Ostrea inornata M. and H.
Inoceramus crispii var. barabini Morton.
Inoceramus vanuxemi M. and H.
Inoceramus sagensis Owen.
Lucina occidentalis var. ventricosa M. and H.
Thetis circularis M. and H.
Anchura (Drepanochilus) americana E. and S.
Nautilus dekayi Morton.
Baculites ovatus Say.
Baculites compressus Say.
Scaphites nodosus Owen (?)
Scaphites nodosus var. quadrangularis M. and H.
Scaphites nodosus var. brevis Meek.
Ptychoceras crassum Whitfield.
Heteroceras (Exiteloceras) cheyennense M. and H. (?).
Heteroceras (Didymoceras) nebrascense.
Heteroceras (Didymoceras) cochleatum M. and H. (?).
Heteroceras sp. undet.
Helicoceras sp. undet.

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[a] Gilbert, G. K., Description of Pueblo quadrangle: Geologic Atlas U. S., folio 36, U. S. Geol. Survey, 1897, p. 7.

*Fox Hills sandstone.*—The Pierre shale gives place abruptly to several hundred feet of sandstone which are supposed to correspond to the Fox Hills formation. These sandstones are most extensively exhibited in the region about Walsenburg and Trinidad, where they are of sufficient hardness to give rise to a prominent escarpment, extending from the south side of the Huerfano Valley to the Raton Mesa. In this district they are known as the Trinidad formation, which here consists of a lower member, 85 to 90 feet thick, of thin-bedded, fine-grained, dark-gray sandstone in layers 2 to 4 inches thick, with thin shale partings, and an upper member, 75 to 80 feet thick, of greenish-gray, heavy-bedded, massive sandstone which weathers to a light-gray color. This upper bed is characterized by numerous remains of the fossil *Fucoid halymenites*, which is easily recognized by the pitted cylindrical casts of the branching stems. In the lower beds occasional poorly preserved baculites are found. The total thickness of the formation is about 150 feet in the vicinity of Trinidad and about 170 feet near Walsenburg. At its top there are usually a few feet of brown sandstone in contact with the overlying Laramie. Near Trinidad the thin sandstone layers of the lower member rarely exceed 3 inches in thickness, except near the base, where there is a prominent bed of coarser sandstone 3 to 5 feet thick. These beds become thicker and coarser northward, and to this is due the expansion of the lower zone. In the district east of Colorado Springs there is only a small thickness of sandstone between the supposed top of the Pierre shale and the lowest coal beds, so that there the representative of the Fox Hills is but scantily developed, unless possibly there should be comprised in it some of the underlying shales; similar conditions prevail in the eastern portion of Elbert County and the northern portion of Lincoln County, where the Fox Hills formation has as yet not been differentiated. In the Florence basin the formation consists of about 400 feet of sandy shales, with a few limestone concretions, capped by a persistent bed of yellow fossiliferous sandstone 10 to 50 feet thick.

*Laramie formation.*—The Laramie formation occurs in three areas in the district to which this report relates. One is in the wide, shallow syncline east of Colorado Springs; the second is in a long, deep syncline south and west of Trinidad and Walsenburg, and the third is in the deep but small syncline near Florence. The rocks are sandstones and shales, and among them at various horizons, especially in the lower beds, are extensive deposits of lignite. The sandstones are mostly massive, soft, and yellowish, 10 to 20 feet thick, with intervening bodies of shales, which are usually sandy and carbonaceous. The thickness varies from 1,000 to 2,500 feet. The Laramie rocks in the basin east of Colorado Springs have not been studied in detail, but in general they present the characteristics above mentioned. The coal is worked from lower beds at several points north, east, and southeast of the city. The Laramie area extends east into the northern portion of Lincoln County, but its limit in that direction was not accurately ascertained, owing mainly to the cover of surficial formations.

In the Florence district the Laramie is composed of a succession of heavy bedded sandstones with intercalated shales, and in the lower portions there are beds of workable coal. These sandstones form an escarpment surrounding the mesa southwest of Florence and constitute one or two small outliers, one of which is known as Castle Rock. In this basin there is more sandstone than shale in the Laramie formation.

In the vicinity of Walsenburg the Laramie formation has a thickness of 1,000 feet, which increases to the southward, due to the thickening of the upper member and to diminished erosion of its upper surface, until at the State line south of Trinidad the thickness is 2,500 feet. The basal beds are shales overlying the Trinidad sandstone. A massive bed of sandstone a hundred feet or so from the base of the formation is persistent, and overlies an alternation of arenaceous shale, clay shale, and coal. Above this massive sandstone the formation is predominantly sandstone, but the sandstones and clay partings vary greatly in thickness. There are two principal groups of coal beds—one between the Trinidad sandstone and the massive sandstone 100 feet above, and the other above this sandstone.

The fossil remains of the Laramie formation are limited to the characteristic *Ostrea glabra*, a unio, and a dinosaur of undetermined genus. It contains a rich subtropical flora, similar to the present-day flora of the Gulf States, consisting of figs (15 species), oaks, ferns, palms, poplars, willows, and tulips. In the region of Golden, Colo., there are 83 species that are peculiar to the Laramie.

### CRETACEOUS(?) SYSTEM.

*Arapahoe formation.*—In the Denver basin the Laramie formation is overlain by 600 to 800 feet of conglomerates, sandstones, and shales, which are separated by an unconformity and by some are believed to be of early Tertiary age. At the base are 50 to 200 feet of conglomerates and sandstones of increasing coarseness toward the mountains, while above are several hundred feet of sandy shales containing irregular masses of sandstones. These deposits extend far south of Denver and appear to be represented in the Monument Park region and east of Colorado Springs, but their limits and relations have not been determined. Apparently the coarser, lower beds increase in thickness to the south. The formation appears to be present in small amount in the Florence basin, where a series of conglomerates and sandstones 250 to 300 feet thick is supposed to represent it. It is a prominent component in the Spanish Peaks basin, where it is represented by all or part of the Poison Canyon formation of R. C. Hills.

*Poison Canyon formation.*—This formation underlies much of the high region rising to the Spanish Peaks between the Purgatory and Huerfano valleys. To the north it is separated from the underlying Laramie beds by marked unconformity, while in the vicinity of Spanish Peaks and southward there appears to have been continuous deposition between the two formations. The thickness is 2,000 feet to the south and 3,500 feet in the extension of the formation northwestward up the Huerfano Valley. The rocks consist of coarse sandstones and conglomerates in beds 10 to 50 feet thick, separated by thinner masses of yellow clay. The conglomerates near the middle of the formation often are not firmly cemented and resemble gravel beds. The overlying sandstones are light gray, weathering pink, while the sandstones lower in the formation are yellowish, with red blotches, but similarly weathering to a pink tint. No fossils have been reported, but, from the relations of the formation, there should be little question that it is approximately the same age as the Arapahoe. Some baculites reported from the section of the beds in Poison Canyon doubtless were found in or were derived from the Pierre shales, which are overlapped by the formation in that region.

*Denver formation.*—In the Denver basin the Arapahoe formation is overlain by several hundred feet of coarse deposits, consisting largely in the lower part of débris of younger eruptive rocks and in the upper part of granitic débris. It also includes local sheets of basalt and volcanic tuffs. Its age may be early Eocene. This formation is not known to extend into the Arkansas basin, but may possibly underlie a portion of the high divide near the foot of the mountains. Some small areas of conglomerates, sandstones, and shales overlie the supposed Arapahoe formation in the Florence basin, but they can not certainly be correlated with the Denver formation. In the higher slopes of the Spanish Peaks area, however, there is a formation succeeding the Poison Creek beds which Mr. Hills has designated the Cuchara formation, and the stratigraphic succession strongly suggests that this may represent the Denver beds.

*Cuchara formation.*—This formation has a thickness of about 500 feet, consisting mostly of massive, yellowish, reddish, or brownish sandstones, with 50 to 100 feet of red, brown, and sometimes white marl, shale, and sand at the bottom. The sandstone is coarse and the conglomerates are often very loosely cemented, the pebbles largely of granite and Carboniferous débris. The formation has yielded no fossils, but the Denver formation has yielded 150 species of plants, only 15 of which are common to the Laramie.

### TERTIARY SYSTEM.

*Monument Creek formation.*—On the high divide between the Platte and Arkansas drainage basins, at the foot of the Rocky Mountains, there is an extensive deposit of conglomerates, sand, sandstone, gravel, and clay, known as the Monument Creek formation. It lies on the Laramie formation to the east and the Arapahoe formation to the west, and at Palmer Lake it abuts against the granite at the foot of the mountain. There are two members, a lower one of sands and clays and an upper one of conglomerate and sandstone. The latter caps numerous buttes and plateaus in the high region west and north of Calhan and north of Monument.

Fossil bones of *Titanotherium* have been discovered by the writer[a] and Mr. C. A. Fisher in the upper member in the region north of Calhan and southwest of Elizabeth, which indicate that this portion of the formation is of Oligocene age. The lower member may be Oligocene, or perhaps Wasatch or Bridger, in age.

*Nussbaum formation.*—Wide areas of the High Plains adjoining the Arkansas Valley in eastern Colorado are mantled by loams, sands, and gravels of late Tertiary age, of which some outlying portions westward have been designated the Nussbaum formation by Mr. Gilbert. These deposits consist of the "Tertiary grit" and "Plains marl" of the Kansas geologists and are supposed to be of Pliocene age. The formation is composed mainly of loose sand and coarse gravel, which on the higher divides eastward has a thickness of more than 200 feet. Locally some portions often consist of a loose sandstone, and frequently the beds are cemented by carbonate of lime into a very sandy limestone ("mortar beds"), occasionally of considerable extent. The most extensive areas cover the High Plains north of Arkansas River to the east of Fountain Creek Valley, and south of the river in Prowers and Baca counties. Small outliers remain on many of the divides south of the river, west from longitude 104° to the foot of the mountains, probably indicating that originally all of the plains region was covered by the formation. In general the deposits have a smooth surface and slope gently to the east, but there is also a slope into the Arkansas Valley, especially near Boone and Fowler, where it approaches near to the river and ends in a prominent bluff. In Kiowa County two distinct terrace levels are exhibited in the slope toward Arkansas River, with underlying Cretaceous beds showing in places in the intervening escarpment. In the high ridge extending east and north from Calhan the western margin of the formation presents a steep front to the west and northwest, in marked contrast to the gentle easterly slopes. The eastern limits of the formation north of Arkansas River are usually indefinite, owing to wash of the deposits down the general slope. South of Lamar the formation caps an elevated smooth-topped ridge and is terminated to the north by an abrupt slope, especially at the head of Clay Creek. To the east it descends rapidly and crosses Two Butte and adjoining creeks.

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[a] Darton, N. H., Age of Monument Creek formation: Am. Jour. Sci., vol. 20, 1905, pp. 178-180.

## QUATERNARY SYSTEM.

*Alluvium.*—The largest areas of alluvium in this district are along Arkansas River below Pueblo. The width of the bottom lands which they constitute varies from three-fourths of a mile to a mile, and the thickness of the deposit is 50 to 60 feet in the central portion of the valley. The materials are mostly fine sands and loams laid down by the river at various stages; in times of flood more or less new material is deposited, especially on the lower flats. Above Pueblo, where the river flows in a narrower valley, the alluvial flats are narrower.

There are alluvial bottom lands along Fountain Creek and nearly all of the larger branches of the Arkansas, the only exceptions being in some of the narrower portions of the canyons in the southwestern part of the area. Higher terrace levels appear in places, capped by sand and gravel, products of an earlier period of Quaternary deposition.

*Dune sands.*—Sands which have been heaped up by the wind occur extensively along the south side of Arkansas River from Las Animas eastward, often in a belt a mile wide. Dunes of considerable prominence are found south of Lamar and Granada. Portions of the Nussbaum formation give rise to sand dunes, notably in the region north of Nepesta and in wide areas in Kiowa, Cheyenne, and Lincoln counties. Between Rush Creek and Big Sandy nearly all of the land is capped by sand dunes derived from the Nussbaum formation.

## IGNEOUS ROCKS.

In the Rocky Mountain Range adjoining the Arkansas Valley are extensive bodies of igneous rocks, mostly of Tertiary age. Those in the vicinity of Pikes Peak and Cripple Creek have been described by Doctor Cross[a] and others. The extensive series of dikes in the Spanish Peaks and adjacent slopes have been described by Mr. R. C. Hills[a] and the reader is referred to these publications for details. The distribution of the rocks is shown in Pl. VI.

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[a] Cross, Whitman, Description of Pikes Peak quadrangle: Geologic Atlas U. S., folio 7, U. S., Geol. Survey, 1894.

The Mesa de Maya and the Raton Mesa consist of remnants of extensive outflows of basalt of late Tertiary or Quaternary age, and in their vicinity are a number of similar smaller outliers of the same material, as shown in Pl. II. On the south side of the Mesa de Maya the basalt is seen to overlie an outlier of later Tertiary gravels, which indicates that the age is post-Pliocene.

In the Two Butte uplift igneous rocks appear, as described by Mr. G. K. Gilbert,[b] in a laccolithic mass and in numerous dikes.

### MANITOU EMBAYMENT.

West of Colorado Springs there is a westward deflection in the Front Range of the Rocky Mountains, in which lies a thick development of the Paleozoic rocks. The recess is about 4 miles deep and is due to a westward trend of the granite on the north side and a profound fault on the southwest side, forming a reentrant angle of which the apex is at Manitou. In Pl. XVI the principal geologic relations are shown, and they are especially brought out by the central cross section on that plate. To the north and south the "Red Beds" usually lie against the granite at the surface, but in the embayment the older limestones and sandstones appear at the surface. It is probable that east of the mountain front these rocks extend far to the north and south, but on either side of the embayment they have been eroded from the granite slopes and overlapped by younger sediments. The embayment probably was a valley at the time of this erosion epoch, and the sediments contained in its deeper portion were not removed. Its southwestern margin has been cut off by the great fault, which uplifted the strata so high that they were long ago removed by erosion.

The embayment continues far to the northwest from Manitou, but the strata which it formerly contained are removed for the first few miles. A small area of "Red Beds" and underlying limestones remains in this area in Manitou Park, on Trout Creek, as shown on the geologic map (Pl. VI). From the vicinity of Manitou northward to beyond Glen Eyrie Creek the basal strata are sandstones and limestones of Cambrian and Ordovician age, and these appear again in a small area west of Monument Park. Most of their features were described by F. V. Hayden and Dr. A. C. Peale,[c] and by Prof. W. O. Crosby,[d] in a detailed account of the Archean-Cambrian contact near Manitou.

The basal bed is a sandstone averaging about 50 feet thick, usually light colored and moderately fine grained in its lower beds, and red or pink with greenish layers in its upper ones. It contains Cambrian fossils (determined by Mr. Walcott as *Obolus* (*Linguella*) *similis*), and more or less glauconite. The sandstone lies on the granite along a remarkably smooth plain, which shows occasional local erosion irregularities, and the contact is sometimes faulted or flexed. Many details of these contact phenomena are described in the paper by Professor Crosby, just

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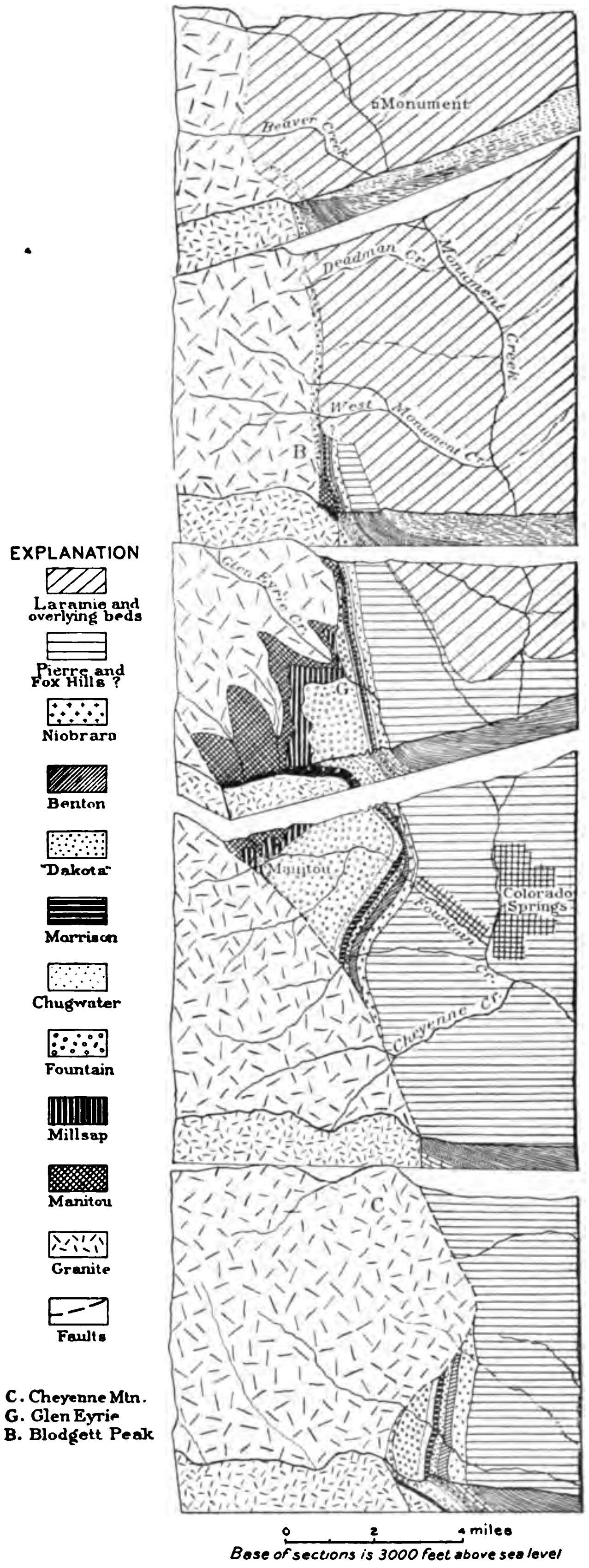
[a] Hills, R. C., Description of Spanish Peaks, Walsenburg, and Elmoro quadrangles: Geologic Atlas U. S., folios 71, 68, and 58.

[b] Gilbert, G. K., Laccoliths in southeastern Colorado: Jour. Geol., vol. 4, 1896, pp. 816-825.

[c] U. S. Geol. and Geog. Surv. Terr., Seventh Ann. Rept., 1874, pp. 193-273.

[d] Bull. Geol. Soc. America, vol. 10, 1899, pp. 14-164, pls. 14-18.



MAP AND CROSS SECTIONS SHOWING GEOLOGIC RELATIONS IN THE MANITOU EMBAYMENT AND TO NORTH AND SOUTH.

referred to. Fine exposures may be seen on both sides of Fountain Creek, which the formation crosses 1½ miles above Manitou, in Williams Canyon, and at Glen Eyrie. The formation dips gently to the southwest and extends for some distance west up the divides between the valleys above mentioned. It ends abruptly at a point a mile north of Glen Eyrie, where it is overlapped by Fountain "Red Beds," but reappears for a short distance in a local embayment a mile farther north, and Mr. W. T. Lee reports it on Deadman Creek southwest of Monument station.

Overlying the Cambrian sandstone are several hundred feet of limestones, of which the lower portion is Manitou, containing Ordovician fossils, while the upper members, according to Professor Grabau,[a] contain Mississippian fossils. This limestone caps the sloping ridges west and south of Manitou and appears extensively in the intervening canyons, especially in Williams Canyon. Its outcrop, together with that of the underlying sandstone, is terminated by overlap of the Fountain formation, a mile north of Glen Eyrie, and reappears in the small embayment west of Monument Park. In this outlier there are exposed, lying on the granite, 30 feet of dark-gray, coarse sandstones, thin bedded and glauconitic at the top, overlain by 20 feet of bright-red, sandy limestone with Cambrian fossils, and by 50 feet of massive, pure, fine-grained, light-gray limestone. On this limestone, which apparently is Manitou, lies an impure limestone varying from gray to buff in color, with a heavy breccia at its base, the latter probably marking an unconformity. The limestones are cut off by a fault, bringing down the Morrison and overlying "Dakota," but a short distance to the north and south the Fountain "Red Beds" are exposed lying directly on the granite.

The Fountain formation occupies a wide area in the Manitou embayment, from Glen Eyrie southward. On the west side of the area the dips are low, but to the east they become nearly vertical, a feature exhibited in the ledges at and near the Gateway to the Garden of the Gods, as shown in Pl. IX, *A*. The rocks consist of coarse sandstones, in part conglomeratic and mostly of red color, although some portions are mottled with gray. The thickness is 1,000 feet or more. From Manitou to Glen Eyrie the formation lies unconformably on the Millsap limestone, but no marked divergence of dip or erosion features was observed. To the south the formation is cut off by a great fault, which brings it in contact with the granite. The outcrop of the formation extends northward from Glen Eyrie, where, as above stated, the red grits directly overlap the granite. In places in their northward extension they are cut off by faults and extensively overlapped by Tertiary formations. At the top of the formation there is the well-marked Lyons sandstone, which gives rise to the prominent white ridge a few rods east of the Gateway to the Garden of the Gods. This formation is overlain by the upper "Red Beds," which I have designated the Chugwater formation. The latter consists mainly of soft red shales with layers of limestone in its lower portion, with a thick bed of gypsum at the top. This gypsum bed is 30 feet thick at the Gateway to the Garden of the Gods, and for some distance north. Owing to talus, faults, and overlaps of younger formations the Chugwater formation is not exposed in the region between West Monument Creek and Perry Park, and southeast of Manitou it is cut off by the great fault.

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[a] Girty, G. H. Carboniferous formations and faunas of Colorado: Prof. Paper U. S. Geol. Survey No. 16, 1903, p.168.

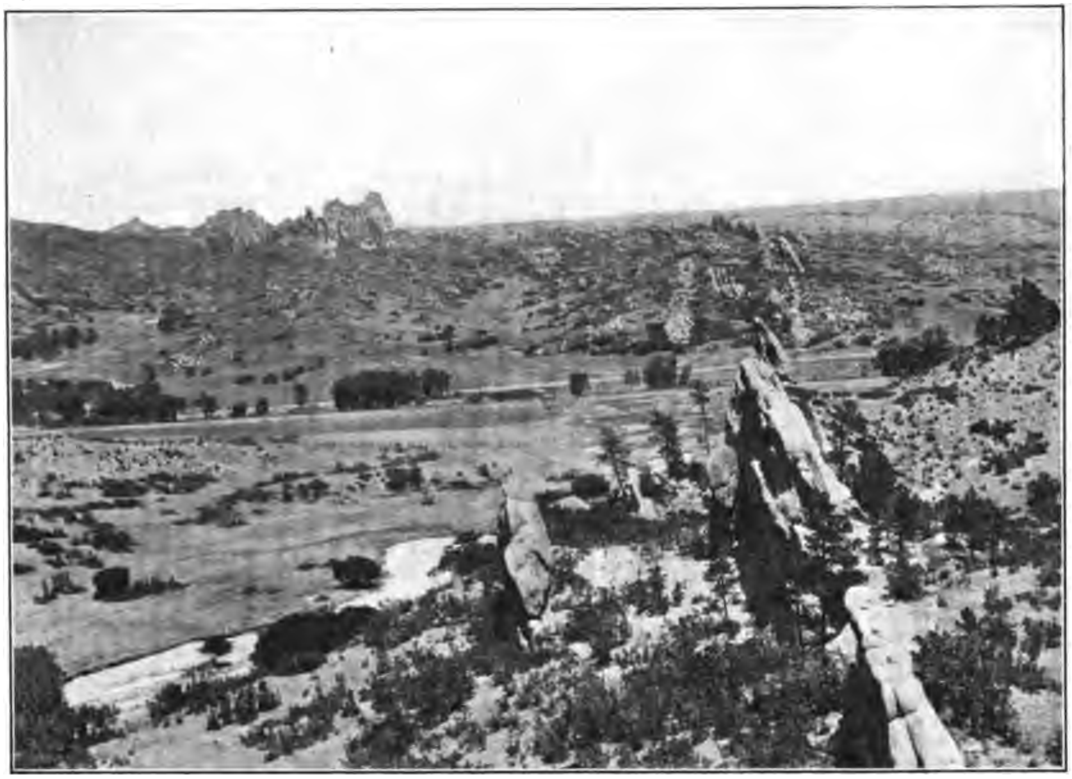
The formations overlying the Chugwater formation in the Manitou embayment are the usual succession of Morrison, "Dakota," Benton, Niobrara, and Pierre, all of which, except the latter, are cut off by the great fault southwest of Colorado Springs. There is also a local interruption in the succession a short distance northwest of Colorado City, owing apparently to a short fault cutting off the "Dakota" and adjoining beds. The Morrison formation west of Colorado Springs exhibits its usual characteristics. Light-colored massive shales predominate, but some fine-grained sandstones and several thin limestone layers are included. Portions of the shale are of grayish-green and maroon tints. The formation lies directly on the 30-foot bed of gypsum at the top of the Chugwater formation. The overlying "Dakota" sandstone varies from 125 to 200 feet in greater part, and is in two massive beds, with shales between. As above stated, the sandstone disappears for a short distance northwest of Colorado City, probably owing to a local fault. The Graneros shale is 240 feet thick. The Greenhorn limestone is well defined and 75 feet thick, consisting of thin beds of limestone with dark shale alternations and containing large numbers of *Inoceramus labiatus*. The Carlile formation, about 250 feet thick, is terminated by the usual bed of sandstone, which is overlain directly by the Timpas limestone. This sandstone and limestone form a prominent hogback extending from north of Glen Eyrie to Bear Creek Canyon, beyond which the Timpas limestone continues nearly to Cheyenne Creek, where it is finally cut off by the great fault.

In the region west of Monument Park the Morrison, "Dakota," Benton, and Niobrara beds appear at intervals, but they are mostly obscured by talus and overlaps. A small exposure of the Timpas limestone appears southwest of Monument station, as shown in Pl. XVI. It dips steeply to the east and appears to be overlapped by Tertiary formations.

### CANYON EMBAYMENT.

*General structure.*—In the region west of Pueblo there is a deep westward deflection or reentrant in the Rocky Mountain Front Range, in which the sedimentary strata extend to a short distance west of the city of Canyon. The granite Front Range, which is so prominent west of Colorado Springs, exhibits an anticlinal structure to the south, and the granite in this anticline pitches beneath the sedimentary strata northeast of Canyon. The sedimentary strata in the syncline on its west side extend northward through Garden Park to the north line of Fremont County, beyond which the granite rises. The prolongation of the anticline, greatly reduced in height, is traceable southward to Huerfano Canyon, crossing Arkansas River 6 miles northwest of Pueblo. The syncline deepens to the south, and in the region southwest of Florence holds a deep basin of Laramie coal measures. Near the south line of Fremont County its western side is faulted so that the Laramie sandstones are in contact with the granite. The west and south sides of the Canyon embayment consist of the Wet Mountain Range, an anticlinal ridge of granite which extends southeastward and finally pitches down near Huerfano River.

In the Canyon embayment are found formations from Cambrian to latest Cretaceous or early Tertiary, presenting considerable complexity in overlap and



*A*. VERTICAL "RED BEDS" NEAR COLORADO CITY, COLO.

Garden of the Gods to the left; ridge of Niobrara limestone to right. Photograph by I. C. Russell.

*B*. MORRISON FORMATION ON GRANITES WEST OF GRAPE CREEK, 4 MILES SOUTHWEST OF CANYON, COLO.

Looking north-northeast. The prominent ledge of sandstone is "Dakota."

structural relations. The principal features are shown in Pl. XVIII. The relations shown north of latitude 38° 30′ are compiled from the Pikes Peak folio by Whitman Cross. The dominant structural features have already been alluded to.

*Garden Park area.*—Oil Creek Valley lies in a syncline pitching southward and exhibiting formations of Ordovician, Carboniferous, and Cretaceous ages. On the west side of the creek, north of Garden Park, is an extensive area of Ordovician limestones and sandstones. At the base is Manitou limestone with a basal cherty and quartzitic portion of Cambrian age lying on the granite and gneiss. Next follows the Harding sandstone, surmounted by long slopes of Fremont limestone. So far as observed, this sequence is general for an extensive area about Garden Park. In portions of the area faults cut out some, or all, of the beds. On the granite slopes east of the creek numerous small outliers occur. The Manitou limestone is 100 feet thick and consists of fine-grained, pink or reddish dolomite with Ordovician fossils. Cherty limestone at the base yields fragments of the trilobite *Ptychoparia*. The Harding limestone consists of fine- and even-grained saccharoidal sandstone in alternating beds of light-gray or pinkish and variegated colors, with a few bands of dark-red or purplish sandy shale. The maximum thickness is about 100 feet. The lower part is sometimes calcareous and locally develops into a thin, fine-grained dolomite. It is succeeded with apparent conformity by the Fremont limestone, which is a bluish-gray or pinkish dolomite of uneven grain, sometimes sandy, weathering to very rough surfaces. Its thickness is about 100 feet, and it is especially characterized by the occurrence of chain coral (*Halysites catenulatus*), which often occurs in masses 2 feet in diameter. It also contains other fossils of later Trenton age.

The Fremont limestone gives rise to long sloping plateaus on the west side of Oil Creek north of Garden Park. At the north end of the park the Fremont limestone is overlain by Millsap limestone in a narrow outcrop about 1½ miles long. Thirty feet of the formation are exposed consisting of thinly bedded, variegated, dolomitic limestone, with a few thin sandstone layers. Chert nodules in the upper limestone layers carry casts of characteristic Mississippian fossils.

The greater part of Garden Park is underlain by the Fountain formation, which reaches a thickness of about 1,000 feet. It lies on the Millsap limestone above mentioned, but overlaps onto the Fremont limestone, presenting unconformable contacts in both cases; for part of its course it is cut off by extensive faults, as shown in Pl. XVIII. The Fountain beds consist of red sandstone, grits, and conglomerates, heavily bedded and with much feldspathic material derived from the adjacent granite. The conglomerate layers contain many pebbles of hard, pre-Cambrian quartzites and of limestones, quartz, and cherts.

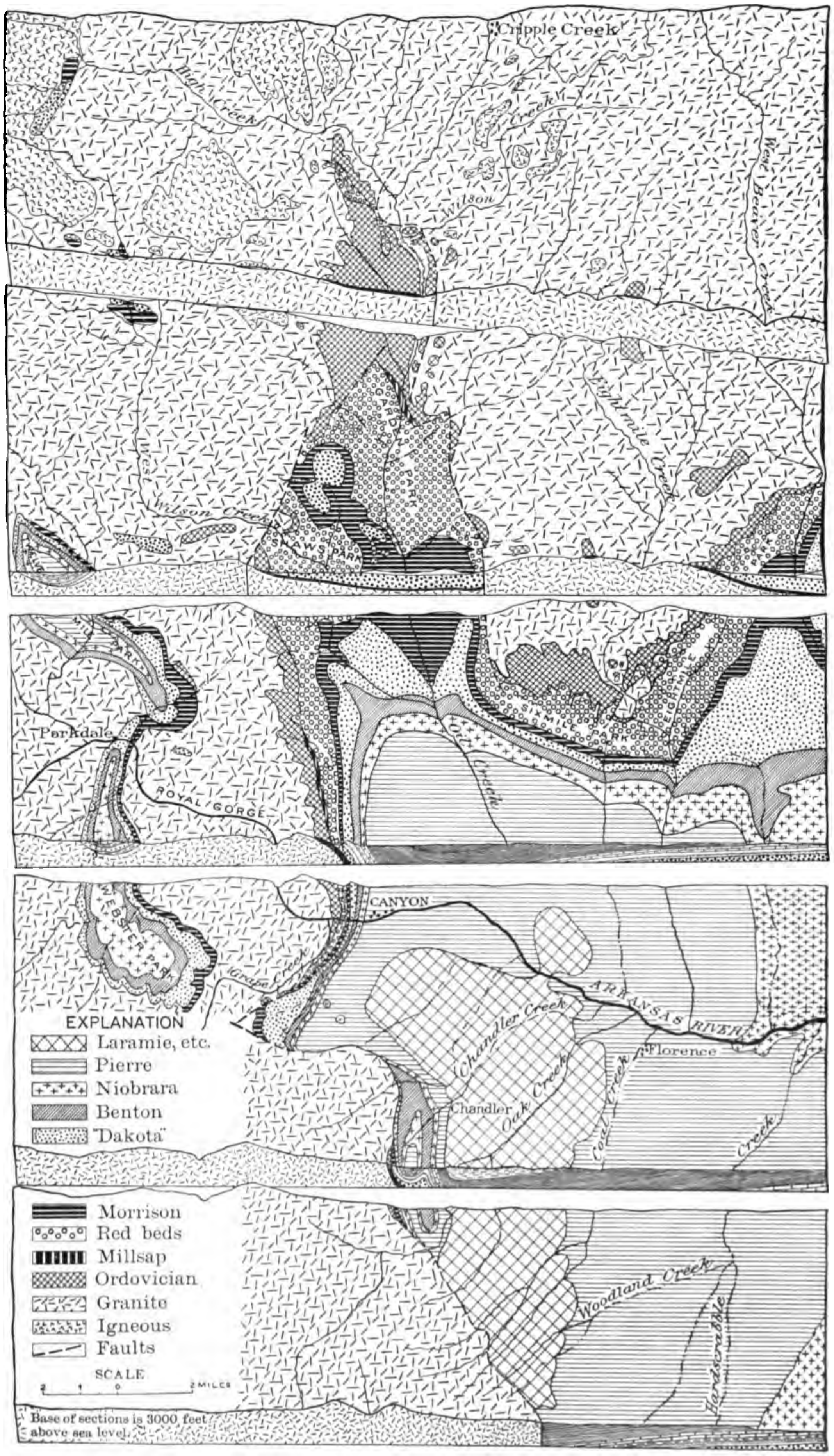
The Morrison formation appears extensively along the south and west sides of Garden Park, where the thickness is about 350 feet. It is separated from the Fountain formation by unconformity, but does not present divergence of dip or evidence of deep channeling. The materials are mainly greenish, pink, or gray shales and marls. Sandstone occurs at the base and also at numerous horizons in the upper part of the section, but the beds vary in thickness and extent. In the sandstone deposits about 100 feet from the top of the series, at the locality shown in Pl. X, *B*, large numbers of saurian remains have been obtained. Fresh-water shells also occur.

Gypsum is locally developed, and a thin limestone occurs in the lower portion of the formation.

The Morrison formation is succeeded in regular order by "Dakota" sandstone, which caps high ridges south and west of the park, presenting its usual characteristics and having a thickness of about 300 feet. Southeast of Garden Park lie Sixmile, Eightmile, and Cemetery parks, valleys which mark the eastward and northeastward extension of the Fountain "Red Beds" across the north end of the Front Range anticline. On the north side of these parks are slopes of Ordovician limestones and sandstones, comprising Manitou and Harding, with Fremont as far east as Eightmile Creek, northeast of which the Fountain formation lies directly on the Harding sandstone. Outliers of Manitou limestone occur at intervals high on the granite slopes north. South of the three parks there is a continuation of the "Dakota" hogback, with Morrison formation in its northern and northwestern slopes. On Eightmile Creek the Fountain and associated formations are traversed by a prominent fault which brings up the granite in two prominent knobs on either side of the creek. On Wilson Creek, 8 miles northwest of Garden Park, some small outliers of Morrison formation lie directly on the granite and gneiss and in part are overlapped by small areas of "Dakota" sandstone. Two similar areas of these two formations occur still farther northwest on the small branch of High Creek. Three miles southwest of Garden Park is Shaws Park, underlain by a zone of Fountain "Red Beds" outcrops which extend southward to Arkansas River west of Canyon. On the west side of this zone the Ordovician limestones and sandstones extend far up the mountain slopes, while on the east side is a hogback of Dakota sandstone with Morrison formation in its western slope. At the north end of Shaws Park there is a prominent fault, which crosses Wilson Creek nearly at right angles and brings formations from Ordovician to Cretaceous into contact with the pre-Cambrian rocks, as shown in Pl. XVIII.

*West of Canyon.*—In the mountain slopes and hogback west of Canyon there is presented the southward extension of the formations of the Garden Park area. The formations all dip steeply to the eastward and there are numerous exposures of all the beds. The high mountain range west, consisting of granite and gneiss, is traversed by Arkansas River in a deep canyon known as the Royal Gorge. On the lower eastern slopes of this ridge the Ordovician rocks are extensively exhibited. The valley of Sand Creek is in the Fountain "Red Beds." The main hogback west of Canyon consists of "Dakota" sandstone, with Morrison formation on its west side and Benton shales on its east slope. There is also a subordinate hogback of small, sharp ridges due to the Timpas limestone of the Niobrara formation. To the east there is a broad, deep basin containing Laramie coal measures.

The principal features of distribution of the formations are shown in the middle portion of Pl.XVIII. On the mountain road 4½ miles northwest of Canyon the Manitou limestone lies directly on the granite. It is 10 feet thick and contains bands of chert. Next above is characteristic Harding sandstone, pink and buff, except at the top, where there is a characteristic succession of reddish shales. The Fremont limestone appears with its usual characteristics, and apparently also the Millsap limestone, although no Carboniferous fossils were observed at this place. The upper portion of the limestone presents a very irregular contact with conglom-



MAP AND CROSS SECTIONS OF "DAKOTA" AND ASSOCIATED FORMATIONS IN THE CANYON EMBAYMENT, COLORADO.

erate beds at the base of the Fountain formation. A typical exposure of this feature is shown in Pl. XX. The conglomerate is about 80 feet thick and is succeeded by about 1,000 feet of red sandstones and grits extending to the base of the "Dakota" hogback. In the vicinity of Harding's quarry, 2 miles northwest of Canyon, the Manitou limestone is seen to have disappeared and it is not found again in the extension of the beds southward. The following detailed section in this vicinity was made by Mr. C. D. Walcott:[a]

*Geologic section of Fremont limestone and Harding sandstone near Harding's quarry, northwest of Canyon, Colo.*

| | Feet. |
|---|---|
| Fremont limestone: | |
| Compact, hard, light-gray limestone, breaking into angular fragments, but with a band of purple and gray calcareo-arenaceous shale at the base, containing a large Trenton fauna | 45 |
| Dark, reddish-brown sandstone | 10 |
| Hard, compact, light-colored limestone with fossils | 45 |
| Gray, siliceous, magnesian limestone, somewhat ferruginous in lower portion; weathers locally to reddish friable rock, except that near base limestone weathers into rough irregular cliffs with many caverns and holes; corals and other fossils | 170 |
| Red and purple fine-grained, argillaceous, arenaceous shale; fish-plate fragments | 2-4 |
| Harding sandstone: | |
| Coarse purplish sandstone in several layers with gray layers above | 11 |
| Gray and buff sandstone | 7 |
| Fine-grained, argillaceous, arenaceous shale | 3 |
| Massive gray and reddish sandstone with thin irregular beds of reddish-brown, sandy shale in lower portion; numerous fish remains | 20 |
| Reddish-brown, sandy shales, partly calcareous in some layers; fish plates and other fossils abundant | 7 |
| Compact, thinly bedded, reddish and gray sandstone passing into a gray and more massively bedded, somewhat friable sandstone that changes at 25 feet up into a purplish-tinted, somewhat coarse, friable sandstone; dip 40° | 33 |
| Coarse, light-gray sandstone | 5 |
| Granite. | |

Overlying the Fremont limestone are 15 to 30 feet of impure variegated banded limestones, with interbedded sandstones and argillaceous beds containing Mississippian fossils. The unconformity between the two limestones representing Silurian and Devonian time is not marked by discordance of dip nor by any noticeable erosion features. On the north side of Arkansas River, at the mouth of the Royal Gorge, the Ordovician beds are well exposed, lying on granite and gneiss and dipping steeply eastward. There is a basal conglomerate merging upward into hard gray to pink sandstones, in part coarse grained, 100 feet or more in thickness. These are succeeded by 80 feet of reddish-brown shales and thinly bedded sandstones, 70 feet of gray to pink sandstones (mostly soft and massive), 8 feet of red shales, 30 feet of gray to pink sandstones (mostly massive), followed by a talus-covered interval of about 100 feet, east of which appear ledges of Fremont limestone merging upward into a few feet of gray sandstone. The latter is overlain by the basal conglomerate of the Fountain formation. On the opposite side of Arkansas River the Harding sandstone is about 200 feet thick and is overlain by about 100 feet of limestones, in part sandy, capped by a 20-foot bed of light-gray sandstone. On the irregular upper surface of the latter lie coarse conglomerates at the base of the Fountain formation. Both the

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[a] Walcott, C. D., Discovery of a vertebrate fauna in Ordovician strata: Bull. Geol. Soc. America, vol. 3, 1892, pp. 155-157.

Harding sandstone and the Fremont limestone end a short distance to the south on Grape Creek, the sandstone terminating at a point about three-fourths of a mile south of Arkansas River. The Fountain formation also thins rapidly, and at a point a mile south of the river is only about 250 feet thick, including a basal red conglomerate. In this vicinity the unconformity at the base of the Morrison is very marked, there being much deep channeling in the "Red Beds" surface.

On the east side of Grape Creek, just above its mouth, there are nearly continuous exposures from the granite to the "Dakota" sandstone. At the base are about 150 feet of massive gray sandstones, pinkish in their upper portion. These are succeeded by about 50 feet of soft gray sandstone, with some limestone layers, 50 feet of limestone (Fremont), 10 feet of red sand and sandstone, about 900 feet of Fountain beds (with conglomerate and arkose at the base), and the massive pinkish-gray sandstone 30 feet thick at the top. The latter is a noticeable feature west and northwest of Canyon. In a small canyon cut through the hogback ridge 1½ miles south of the mouth of Grape Creek there are extensive exposures. On the west there is, first, the granite, overlain directly by red and gray conglomerates and grits of the Fountain formation, here not over 30 feet thick; then follow Morrison shales about 300 feet in thickness, presenting the usual characteristics. The "Dakota" sandstone presents the features shown in Pl. X, *A*. It has a lower member, 90 feet thick, of massive buff sandstone; a middle member, 100 feet thick, of dark-gray shales[a] with buff sandstone partings, and an upper member, 100 feet thick, of massive buff sandstone which rises to the crest of the hogback ridge. The upper portion of this member grades into the Graneros shales through about 15 feet of beds of passage. The Graneros formation is 250 feet thick and is succeeded by 50 feet of typical Greenhorn limestone in thin layers with shale partings. Large numbers of *Inoceramus labiatus* occur in the upper portion of the limestone.

The Carlile formation consists of 200 feet of dark shale, with 2½ feet of sandy limestone with oysters at the top. The basal portion of the Timpas limestone is in massive beds 30 feet or more thick, followed by 600 feet of Timpas and Apishapa beds. Much shale occurs in the lower and middle portion of the latter, and the usual bright-yellow weathered beds at its top.

The "Dakota" hogback extends southwestward to the granite slopes at the foot of the Wet Mountain Range, where all of the strata from the Morrison to the basal Pierre are cut off by the east-west fault, as shown in Pl. XVIII. Along the main road from Canyon to Webster Park, on the hillside above the last big bend in Grape Creek, there is a well-marked fault cutting off the "Dakota" sandstone on the west and bringing it into contact with two small masses of limestone, apparently Fremont, underlain by sandstone, probably Harding, which lies directly on the granite to the west. A short distance south of where the road crosses this fault the "Dakota" sandstone is seen to be underlain by the Morrison formation, which lies directly on granite, showing a definite overlap. This relation is repeated on the west side of Grape Creek, as shown in Pl. XVII, *B*. In both of these contacts the dips are very low, and faulting is out of the question.

Four miles due south of Canyon the Pierre shale appears to extend directly to the granite, from which it is apparently separated by the extension of the fault which

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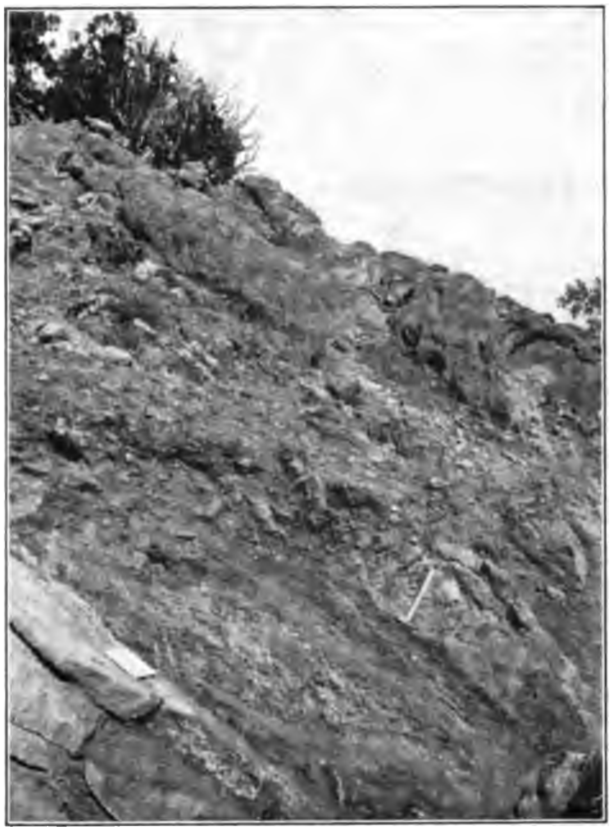
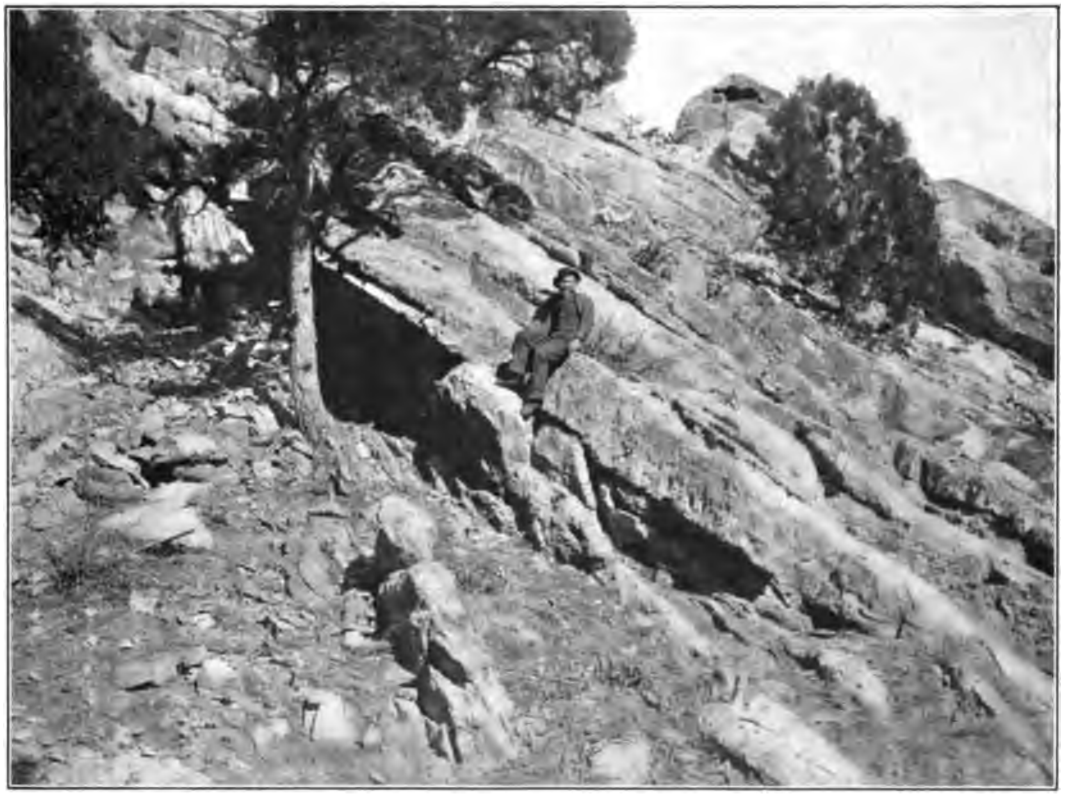
[a] In the summer of 1905 Mr. Stanton discovered Comanche fossils in these shales.



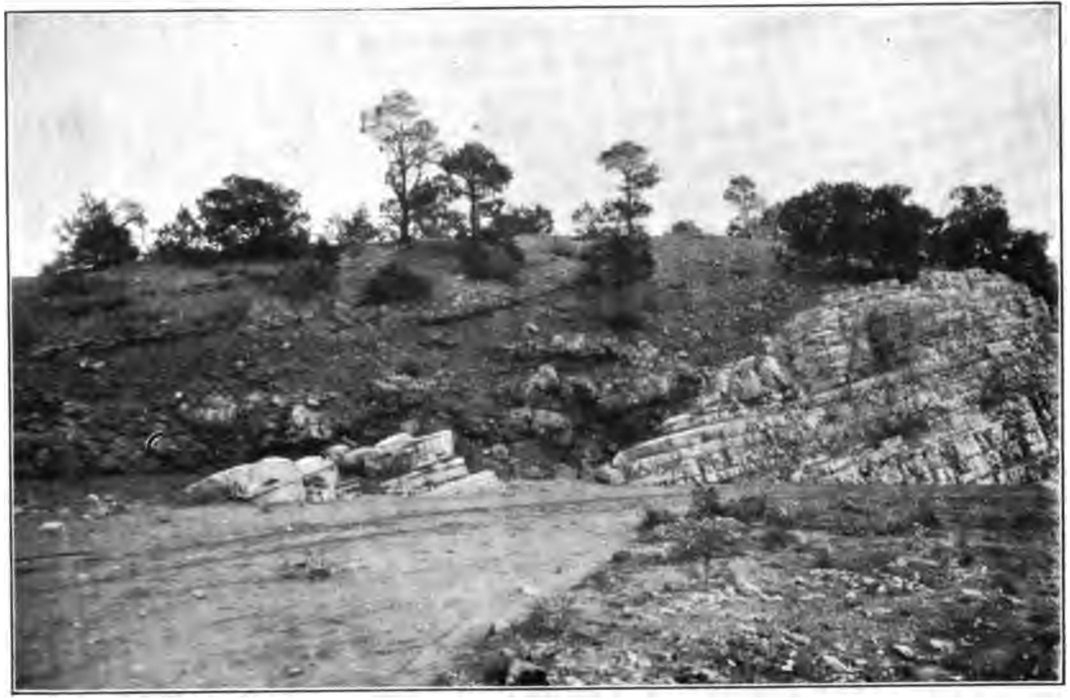
*A.* SHALE MEMBER LYING BETWEEN TOP OF HARDING SANDSTONE AND BASE OF FREMONT LIMESTONE ON MOUNTAIN SLOPE NORTHWEST OF CANYON, COLO.

Photograph by C. D. Walcott.

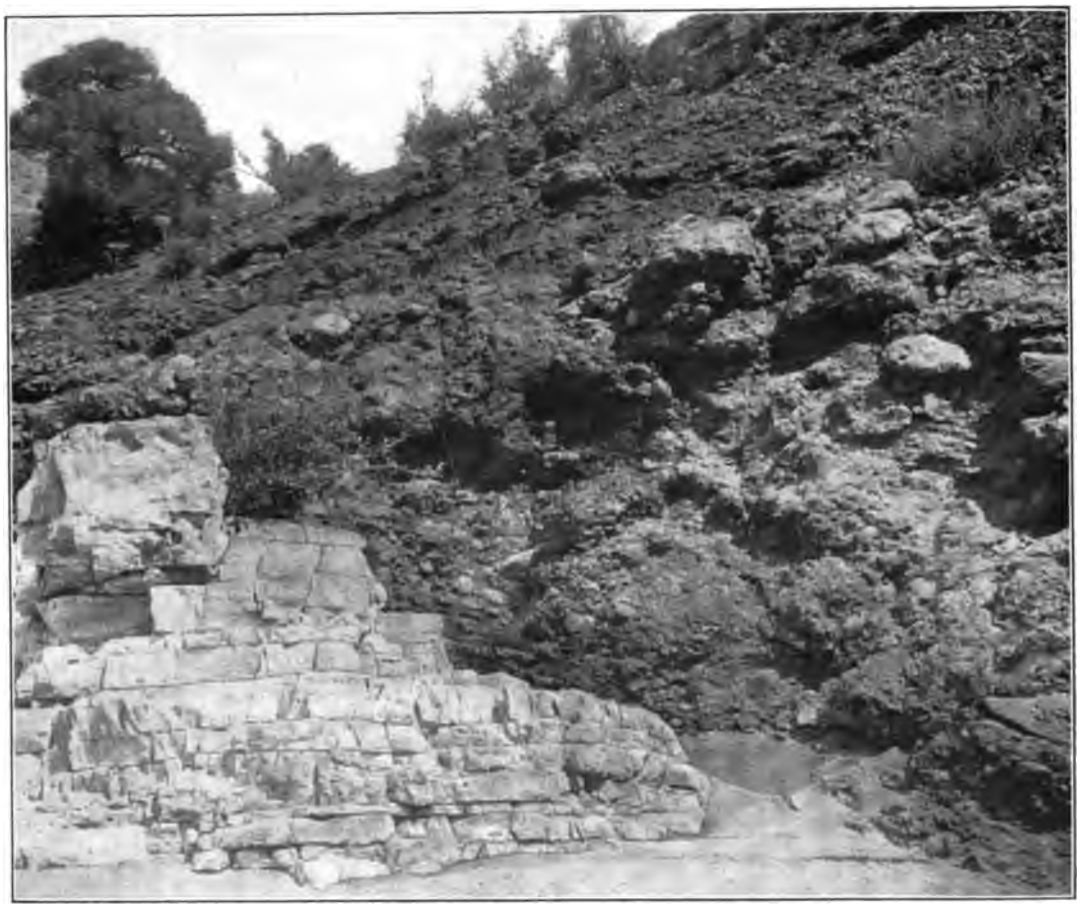


*B.* HARDING SANDSTONE ON GNEISS AND SCHISTS 1¼ MILES NORTHWEST OF CANYON, COLO.

Looking north from below spring west of Harding's quarry. The man's feet are on the contact. Photograph by C. D. Walcott.



*A*



*B*

CONGLOMERATE AT BASE OF "RED BEDS" LYING UNCONFORMABLY ON MILLSAP LIMESTONE, 4 MILES NORTH-NORTHWEST OF CANYON, COLO.

Looking northeast.

cuts off the "Dakota" sandstone and overlying formations along the foot of the mountains westward. The fault appears to die out at the point where the main mountain slope turns abruptly to the south. In this vicinity the "Dakota" sandstone and overlying formations reappear at first in a steep-dipping monocline with Laramie sandstones less than a mile distant from the granite. At one point 2 miles northwest of Chandler the "Dakota" sandstone lies directly on the granite and is overlain by 400 feet of Benton shales, including the Greenhorn limestone and 25 feet of sandstone at the top of the Carlile formation, on which lies the Timpas limestone. West of Chandler a syncline and anticline develop, the latter marked by a prominent ridge, which is due to the top sandstone of the Carlile and the overlying Timpas limestone. These flexures extend nearly to Oak Creek, where they die out. Near the foot of the mountain slope, 2 miles southwest of Chandler, the "Dakota" sandstone is underlain by 300 feet of Morrison shale, under which for a short distance the Harding sandstone and the Fremont limestone appear. The following section was measured by Mr. C. E. Siebenthal, in beds dipping 80°:

*Geologic section 2 miles southwest of Chandler, Colo.*

| | Feet. |
|---|---|
| Morrison shale | 300 |
| Massive white limestone | 40 |
| Massive, red, dolomitic limestone | 40 |
| Red shale and brown sandstone, with fish scales | 25 |
| Hard and soft sandstones, interbedded | 30 |
| Granite. | |

A short distance south of this locality a fault develops which cuts off the Morrison, "Dakota," Benton, Niobrara, and Pierre beds in succession and immediately south of Oak Creek brings the Laramie beds into contact with the granite. This relation continues to the southern margin of Fremont County, or to a mile south of Neulan Creek. At the southern margin of Pl. XVIII, which is about a mile south of the southern margin of Fremont County, the Pierre shale and granite are in contact along this fault line.

## EAST SIDE OF GREENHORN MOUNTAIN.

Greenhorn Mountain is a southern extension of the Wet Mountain Range, and it terminates southward in a south-pitching anticline, in the same manner as the eastern Front Range does northeast of Canyon. Along its east side, from Hardscrabble Creek to its southern termination at Huerfano River, a considerable variety of overlap relations are presented. The principal features are shown in Pl. XXII (constructed largely from the Walsenburg and Pueblo folios). The lowest beds exhibited appear only in small outliers west of Beulah, where a white sandstone about 30 feet thick is found, supposed to represent the Harding limestone, lying upon gneiss and overlain by limestone supposed to represent the Millsap. Of the limestones 175 feet are exhibited, consisting of gray and purple rocks with some shale, especially in the lower part. The limestone is classified as Millsap by the occurrence of *Spirifer rockymontana*, which appears in the middle of the series, but it is possible that the lower beds are Ordovician. The Fountain formation appears extensively along the valleys of North and South creeks, at the head of Red Creek, and to a limited extent on Hardscrabble Creek. The rocks consist chiefly of brownish-red sandstones, mostly of coarse texture and containing a considerable proportion of feldspar grains. The upper beds include red and chocolate-brown shale, and at the base there is much coarse conglomerate containing pebbles and bowlders of granite and gneiss. Near Beulah the strata dip eastward at angles of 10° to 20°; the outcrop has a breadth of about 1½ miles, and the thickness of the formation is about 2,000 feet. Four miles south of Beulah the Fountain formation is cut off by a fault. On the head of Red Creek the thickness is much less, and north of Hardscrabble Creek it is in places not over 20 feet thick and is occasionally overlapped by the Morrison formation.

At the south end of the Greenhorn Mountain Range, under the Morrison formation, there appear about 200 feet of red sandstones, which have been termed the Badito formation by R. C. Hills, who states that it apparently corresponds to part of the Fountain formation. The lower half of the formation consists of very coarse brownish-red conglomerate, and the upper part is a brick-red sandstone, generally massive, but in part thin bedded. The Morrison formation appears at intervals along the east side of the Greenhorn Mountain Range, usually lying on the Fountain formation but overlapping the granite on Muddy Creek and near the south end of the mountain. At St. Charles Canyon it is in contact with the granite, apparently because of a fault. The rocks are chiefly massive clays of light color, with thin beds of limestone, sandstone, and gypsum. The lower beds are mostly white and the upper ones chocolate-brown and maroon. On the slopes of Hogback Mountain the formation consists chiefly of red shale with a few layers of hard red sandstone, in all about 70 feet thick. Near the southern end of Greenhorn Mountain the Morrison formation is 270 feet thick and dips steeply down the mountain slope. The lower beds consist of about 60 feet of soft white sandstone having a conglomerate layer at the base. "This is followed by hard shaly beds of pinkish and greenish tints, which break into fragments with conchoidal fracture. The upper portion consists of variegated shales and clays alternating with bands of hard, fine-grained limestone, often containing vermilion-colored cherts. One band of conglomerates a few feet thick contains green pebbles. At one point the basal sandstone overlaps the Badito formation and rests on the gneiss at an angle of 15°."[a]

The "Dakota" sandstone extends along the foothills from Adobe Creek to the end of the mountain just north of Huerfano River, except for a short distance near Muddy Creek, where it is dropped by a fault. To the south it lies directly upon the granite, but at St. Charles Canyon and northward it is underlain by older sedimentary rocks, and this also is the case at the south end of Greenhorn Mountain. On the headwaters of Muddy Creek the formation spreads out extensively in a shallow basin, as shown in Pl. XXII, where it appears lying directly on the granite. The outcrop is also of wide extent on St. Charles River and northward to Red Creek. In Barton Park the formation occupies a shallow syncline which crosses Hardscrabble Creek near the junction of North and South forks. Just east of this place the anticline east of the syncline pitches down and at Greenwood the "Dakota" sandstone gives rise to a prominent anticlinal ridge. The formation presents its usual features of a light-colored, massive sandstone partly coarse grained, especially in the lower beds, where there is more or less conglomerate; the color is mostly

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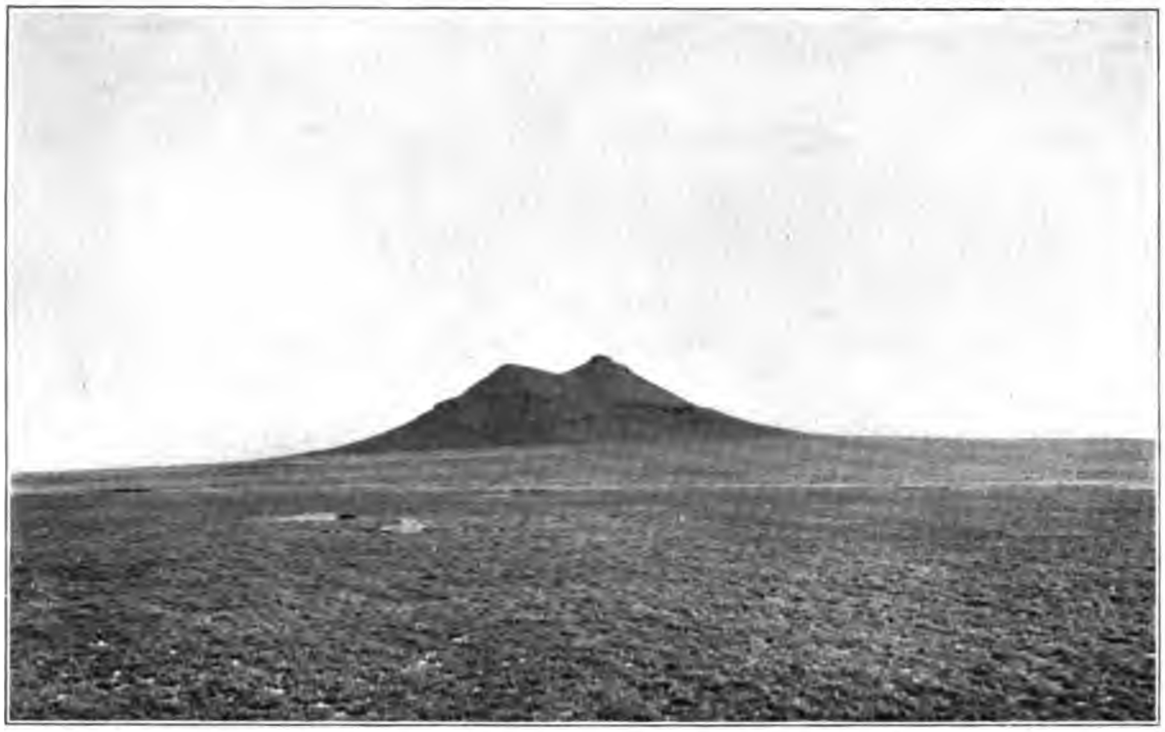
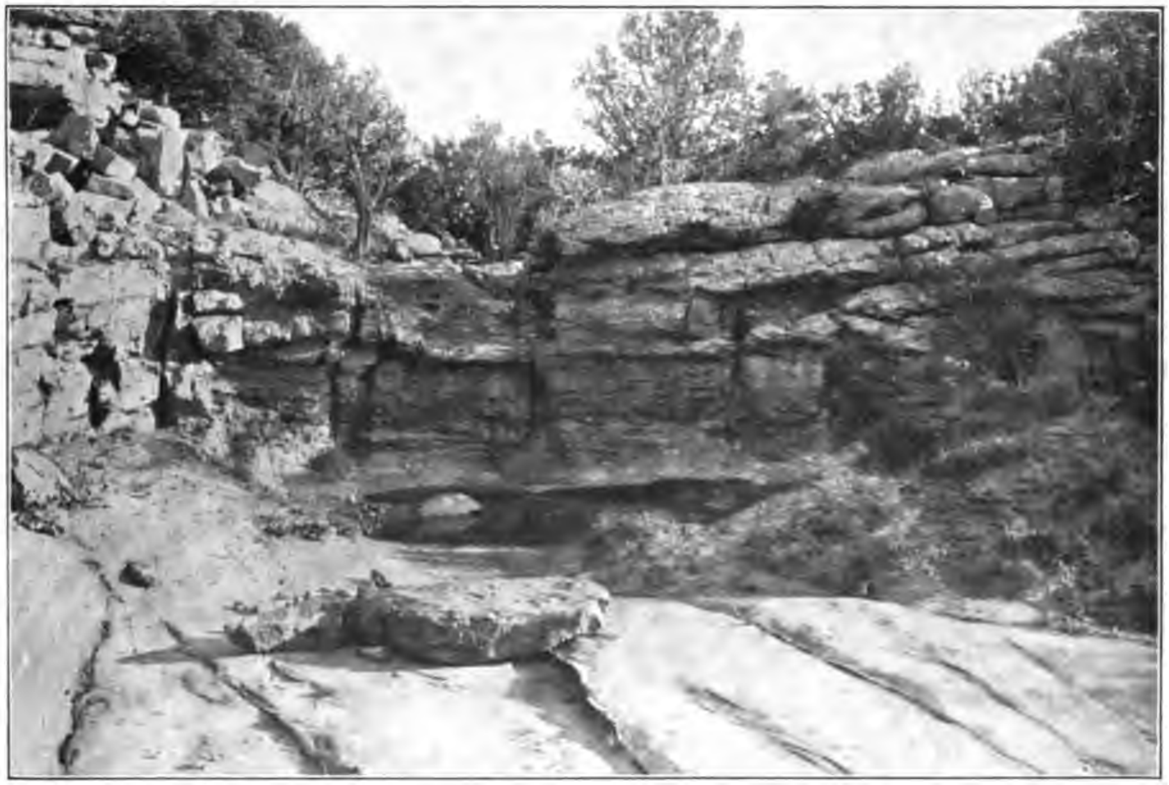
[a] Hills, R. C., Description of the Walsenburg quadrangle: Geologic Atlas U. S., folio 68, U. S. Geological Survey, 1900, p. 1.



*A*. TWO BUTTE, IN SOUTHWEST PROWERS COUNTY, COLO.

Exeter sandstone at top of "Red Beds" uplifted by igneous intrusion.



*B*. WATER HOLE IN "DAKOTA" SANDSTONE NEAR THATCHER, COLO.

pale buff. Considerable shale is included at some localities, especially in the middle of the formation. The thickness varies. In the vicinity of Beulah Mr. Gilbert reports 650 feet, consisting almost entirely of sandstone. Farther north and south the thickness averages about 300 feet. Along the southern slopes of Greenhorn Mountain there is included in the lower half of the formation a persistent bed of gray shale 8 to 10 feet thick. The upper sandstones, aggregating 100 to 150 feet in thickness, are light gray when unweathered, of fine grain, close texture, and regular bedding. "The lower two-thirds of the formation consists, as a rule, of yellowish-gray sandstone of a coarse, porous texture, and some of the layers are really fine conglomerate. Cross-bedding is rather common."[a]

The Graneros and Carlile formations, with the intervening Greenhorn limestone, extend all along the east side of the range and present no special features of stratigraphy or overlap. They are traversed by numerous faults, especially in the area between Greenhorn and Rush creeks, as shown in Pl. XXII.

## GEOLOGIC HISTORY.

The Great Plains region is underlain by sedimentary rocks affording a record of physical geography from Cambrian time to the present, but owing to the lack of knowledge of the relations of some of the deeply buried rocks and to our imperfect interpretation of many features of different geologic epochs, only an outline of the general sequence of events can be given. One significant feature is that some of the conditions were widespread, for there is remarkable uniformity in the resulting products. There were undoubtedly many marine submergences and several periods of emergence in which the surface was sculptured by running waters, especially in the later epochs.

*Cambrian.*—During early Cambrian time a large part of west-central United States was a land surface. In middle Cambrian time there began the development of an interior sea which finally reached the Rocky Mountain province, where it had an irregular shore line about a great series of archipelagoes. From the ancient crystalline rocks of these shores waves and streams gathered and concentrated sands and pebbles, which were deposited as a widespread sheet of sandstone and conglomerate on seabeaches, partly in shallow waters offshore and partly in estuaries. In some areas there are exposures in which these sediments, containing much local material, may be seen abutting against the irregular surface of the crystalline rocks which formed these shores. The central portion of the Black Hills was probably an island in the earlier stages of this period, and, as Mr. Emmons has shown, the Laramie Range and the Rocky Mountain Front Range were for a long period highlands rising out of the Cambrian sea. In the northern portion of the province thick masses of deposits accumulated as submergence progressed in middle Cambrian time, but it is not known that this deposition extended into eastern Colorado. The scanty deposits of later Cambrian age appearing near Manitou and Canyon indicate that the waters finally reached the line of the present Rocky Mountain Front Range. As these deposits lie in embayments which probably were connected with wider areas of open waters, doubtless there was a wide area of later Cambrian deposition eastward under Colorado.

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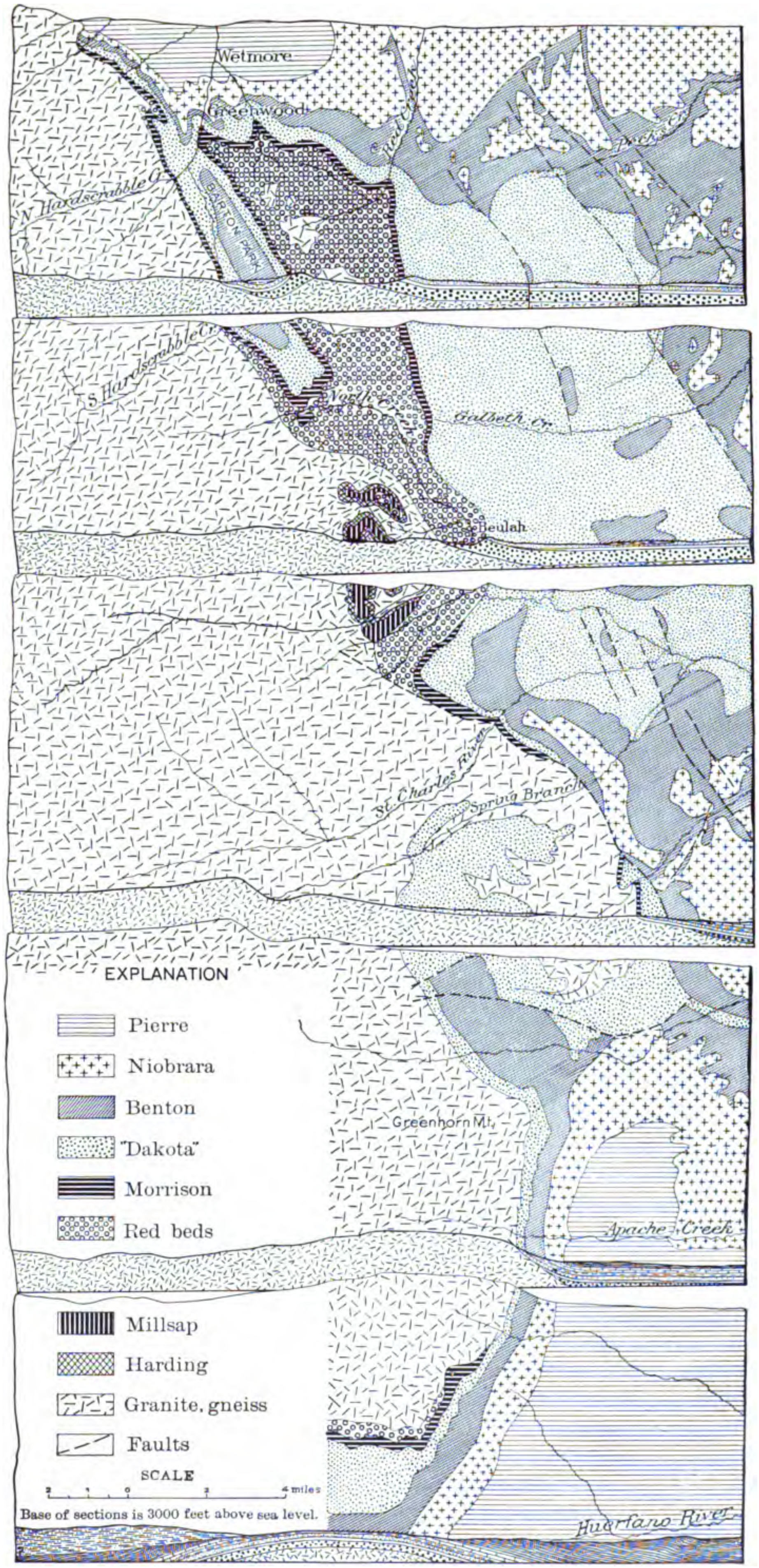
[a] Hills, R. C., Description of the Walsenburg quadrangle: Geologic Atlas U. S., folio 68, U. S. Geol. Survey, 1900, p. 1.

*Ordovician.*—Apparently the submergence above described continued with similar shore lines through a portion of Ordovician time, for the later Cambrian and earlier Ordovician appear to have about the same limits in the exposures in the embayments above mentioned. Doubtless to the east of the Rocky Mountain front there was extensive deposition of the lime sediments such as appear in the outcrops, and these may attain considerable thickness under eastern Colorado. Except in the embayments, the western shore apparently was located east of the extensive "Red Beds"-granite overlap. Perhaps the deposits originally extended farther west all along the slopes and were removed by later erosion along the steeper shores, leaving remnants or projections in the embayments where the erosive forces were less vigorous.

*Silurian-Devonian.*—From the close of the Ordovician to the time of the early Carboniferous sea the uplifts along the western margin of the Great Plains region present no geologic record, the Silurian and Devonian being absent throughout. This is probably because there was an extensive but very shallow sea, or land so low as to leave no noticeable evidence of erosion. Whether it remained land or sea, or alternated from one to the other condition, the region shows no evidence of having undergone any considerable uplift or depression until early in Carboniferous time, when there was a decided subsidence, which established relatively deep water and marine conditions generally throughout the region.

*Carboniferous sea.*—Under the marine conditions of the early Carboniferous there were laid down calcareous sediments, which are now represented by several hundred feet of nearly pure limestone, exhibited in the Black Hills, the Bighorn Mountains, and the Hartville uplift, and, with less thickness, in isolated areas in Colorado. Along the Rocky Mountain front in Colorado the Millsap limestone, representing the Lower Carboniferous, appears at only a few points, apparently in estuaries which extend west of a general shore line now buried under the Upper Carboniferous sediments by the overlap of the latter on the crystalline rocks. In the later part of earlier Carboniferous time there was uplift, resulting in shallower waters, with sediments of mixed limy and sandy nature in some portions of the region to the northwest, while along the Front Range, in Colorado, there was recession of the shore lines to an unknown distance eastward, a condition indicated by pronounced unconformity at the top of the Millsap limestone.

During Pennsylvanian or later Carboniferous times the shore line extended along the foot of the present Rocky Mountain Front Range, and the coarse red sediments of the "Red Beds" were laid down in part on a granite floor. There were strong currents, and possibly at some stages estuaries and swift-flowing streams. Shallow waters extended far to the east, and especially to the southeast, but finally the depth increased somewhat in these directions, the coarse deposits giving place in greater part to limestones and shales. Limestones also appear to the north in Wyoming and southward toward New Mexico, so that the principal area of deposition of the coarser shore deposits was between Huerfano River and the Wyoming line. In Permian time there was a shallow basin which extended across the western portion of the Central Plains region and far to the northwest. In this basin were laid down the great mass of red shales of the Chugwater formation, or upper "Red Beds," with their extensive interbedded deposits of gypsum, presumably products of an arid cli-



MAP AND CROSS SECTIONS SHOWING RELATIONS OF "DAKOTA" AND ASSOCIATED FORMATIONS ON EAST SIDE OF WEST MOUNTAINS, COLORADO.

mate. The sandy clay of this formation accumulated in thin layers to a thickness of 500 to 1,000 feet in Wyoming and the Black Hills, but is much thinner in Colorado. There is such uniformity of the deep-red tint that it is undoubtedly the original color, and this color is present not only throughout practically the entire outcrop of the formation, but also throughout its entire thickness, as is shown by deep borings. It is, therefore, not due to later or surface oxidation. This deposition of red mud was interrupted from time to time by chemical precipitation of comparatively pure gypsum in beds ranging in thickness from a few inches to 30 feet, often free from mechanical sediment. It is apparent that these beds are the products of evaporation while mechanical sedimentation was temporarily suspended, a condition indicative of greatly diminished rainfall; otherwise it is difficult to understand their nearly general purity. Most of the red deposits were laid down in shallow water, so that there must have been subsidence which kept pace with deposition most of the time.

To the southeast, in Kansas and Oklahoma, there was deposited simultaneously with the gypsiferous "Red Beds" a part, at least, of the dark shales into which they merge. These shales, which are of Permian age, contain thick deposits of salt and scattered deposits of gypsum at various horizons. Apparently also to the southeast some of the lowest "Red Beds" deposits are represented by limestones of the lower members of the Permian, the products of deeper marine waters. Whether this deposition of the "Red Beds" extended into or through Triassic times in the Central Plains region is not known, but evidently it was terminated by uplift which brought the region above water. Probably this condition extended through the latter part, if not all, of the Triassic and through Jurassic time, during which there was no deposition and probably some slight erosion. South of the vicinity of the Wyoming line this interval is represented by the general hiatus between the upper "Red Beds" and the Morrison deposits.

*Cretaceous.*—East of the Rocky Mountains Morrison sedimentation was in a long, relatively narrow trough extending along the west side of the Great Plains. This trough was occupied by a shallow body of fresh water which deposited mixtures of clay and fine sand, with thin, irregular bodies of coarser sand deposited by streams or along shores and with occasional thin beds of impure carbonate of lime. Huge saurians were numerous, as shown by the frequent occurrence of their remains in the deposits, although it is possible that this abundance is due mainly to increased mortality or more favorable conditions of preservation, or both.

Morrison time was succeeded abruptly by a change to conditions under which coarse-grained, cross-bedded, massive Dakota-Lakota sandstones were deposited. Although the deposits change abruptly and there was local channeling of the surface of the soft Morrison deposits, the erosion appears to be of remarkably small amount and no more than would be expected to result from the strong currents bearing coarse sands and pebbles.

It is believed that there was no great uplift-erosion interval following Morrison deposition, for if there had been the soft deposits would have been widely removed. As it is the Dakota-Lakota sandstones lie on a uniform series of Morrison sediments from Montana to New Mexico and Oklahoma. It is a significant fact also in this connection that some of the saurians of Morrison time appear to have continued into the next epoch. In the region in southeast Colorado, western Kansas, and a wide area southward, where the Morrison formation is absent, there probably was dry land during Morrison time, but there may have been deposition of more or less Morrison sediments which were afterwards removed by erosion in an early Cretaceous uplift. Marine conditions followed, during which the great Comanche series was accumulated. Farther north and west in Comanche times there was at first a land surface and then shallow waters, in which were deposited the sands now constituting the Lakota sandstone. This was followed by deeper waters, with widespread deposition of the material of the fire clay (Fuson) separating the Lakota and Dakota sandstones. Next came a recurrence to conditions similar to those of Lakota time, and the Dakota sands were laid down, marking the beginning of later Cretaceous time. The Lakota and Dakota sands were derived from various sources, probably to the west, and spread by strong currents in two thick deposits separated by the interval of invasion of deeper water and cessation of strong currents, in which the widespread intervening fire clay was laid down. The sandstones overlap the granites in portions of the region—for instance, southwest of Pueblo and north of Canyon—and there are other places in the granite area from which the sandstones evidently have been but recently removed. These features indicate the position of a portion of the shore lines at least. The extent of the Lakota, as separated from the Dakota, not having been ascertained, except that both are present in the Black Hills region and that the Lakota is surely absent in east Nebraska and east Kansas, their relative areas of deposition can not yet be indicated. The vast extent of this coarse sandstone formation is a wonderful feature, and it is difficult to picture the conditions under which it accumulated. The writer formerly thought that there might have been a shore line progressing gradually westward, with coarse deposits near shore and fine deposits in the deepening waters east, so that the "Dakota" sandstone in western Kansas, for instance, might be represented by shales in central Kansas, but as the very characteristic Benton stratigraphy and the "Dakota"-Benton relations are so uniform over the entire area this hypothesis is untenable.

Following the deposition of this great sheet of sandy sediments there was a rapid change to clay deposition, of which the first representative is Benton shale, a formation even more extensive than the underlying "Dakota" sandstone. This represents the later Cretaceous submergence, in which marine conditions prevailed, and it continued until several thousand feet of clays were deposited, during the Benton, the Niobrara, and the Pierre epochs. In Benton times there were occasional deposits of sand and one thin, but very widespread, deposit of carbonate of lime—the Greenhorn limestone—near the middle of the Benton sediments. The shale of the Benton is followed by several hundred feet of impure chalk, now constituting the Niobrara formation, and this in turn by many hundred feet of Pierre shale, which thickens rapidly to the west, attaining 1,200 feet or more in western South Dakota and over 7,000 (?) feet adjacent to the Rocky Mountains in a limited area west of Denver.

The retreat of the Cretaceous sea, which corresponds with the Fox Hills epoch, resulted in extensive bodies of brackish waters, which spread sands over the clay beds, and then of fresh waters, which deposited the sands, clays, and marsh material of the Laramie. Apparently these last-mentioned formations were not laid down much east of longitude 101°, for they thin rapidly to the east, although, as we do not know the extent of post-Laramie erosion, their former limits can only be conjectured.

*Post-Laramie conditions.*—There was extensive uplift in the Rocky Mountain province following Laramie deposition. This fact is clearly indicated in some areas in the mountains, where the next succeeding deposits lie on an eroded surface having the general outlines of the present configuration, a relation which shows that some of the mountain uplifts were truncated and the larger outlines of topography established by earlier Eocene time. This erosion was largely effected by streams which had strong declivities due to the uplifts. The earliest deposits were the coarse beds of the Arapahoe and Poison Creek formations, which mark one subperiod of uplift and deposition, the Denver, Cuchara, and Huerfano formations marking another. Later, after the outlines of the great mountain ranges to the north and west had been carved, there was a long period in which streams of moderate declivity flowed across the central Great Plains region. These, with frequently varying channels and extensive local lakes, due to damming and the sluggish flow of the waters, laid down the widespread mantle of the Oligocene, or White River and Monument Creek deposits. These began with the sands, which show clearly the course of old currents by channels filled with coarse sandstone and areas of slack water and overflow in which fuller's earth and other clays were laid down. The area of deposition of this series extended across eastern Colorado and Wyoming and western Nebraska and South Dakota, and probably also farther north, for the deposits have been found in western Canada. Doubtless the original extent was much wider than the area in which we now find the formation, for much has been removed by erosion.

At the beginning of Miocene time the general conditions had not changed materially, but doubtless for a while an extensive land surface existed in the Central Plains area. To the north the stream channels extended across this surface, and running water laid down a widespread sheet of sands derived from the mountains to the west. Probably the streams were aided, to a minor extent, by winds. The streams of this time shifted their courses across the plains, spreading the débris from the mountains in a sheet which in some portions of the area attained a thickness of 1,000 feet—a flat alluvial fan of wonderful extent. This is the Arikaree formation, which buried some of the lower ranges of mountains to the north. It was followed by uplift, and by erosion which removed the Arikaree and parts of the underlying formations from the south and the east, leaving the thickest mass of the deposit in western Nebraska and eastern Wyoming. Probably, however, it never was thick nor widespread to the south, erosion predominating in that part of the area during deposition to the north. Next came the epoch in which the streams began depositing the thin mantles of sands of the Ogalalla-Nussbaum and other late Pliocene formations, especially in southern Colorado, southern Nebraska, Kansas, and regions farther south. At this time deposition appears to have been mainly in the south, erosion probably predominating farther north.

These alternating conditions of later Tertiary deposition and erosion, first in the north and next in the south, were undoubtedly determined by differential uplift, the uplifted region suffering erosion and the depressed or stationary region receiving deposits from streams which did not have sufficient declivity to carry off their loads. This condition also is a feature of the semiarid climate of the Great Plains, the mountain torrents and resulting vigorous erosion furnishing large amounts of débris, which the streams of low declivity and constantly diminishing volume were unable to carry to the sea. Even if such a region is traversed by valleys cut during a time of uplift or increased rainfall, when cutting ceases these valleys are soon filled by sediments, and when they are full the streams, at times of freshet and to a less extent in the dry portion of the year, shift their courses so as finally to spread a wide mantle of deposits over the entire area in which there is sluggish drainage.

*Quaternary.*—During early Quaternary time there was uplift and floods from increased precipitation, causing widespread denudation and trenching of the preceding deposits. The smooth, high plain mantled by the Ogalalla-Nussbaum formations, which originally extended to the foot of the mountains, was deeply trenched and widely removed, especially along the Arkansas and Platte valleys. These were wide and very shallow at the end of Tertiary time, when the present drainage system was outlined, but they were cut deeply in the succeeding uplift and the smaller side valleys were then developed. The two large streams east of the mountains have since cut their valleys to a low gradient and in times of flood build up their flood plains, but the smaller streams are still cutting.

## UNDERGROUND WATERS.

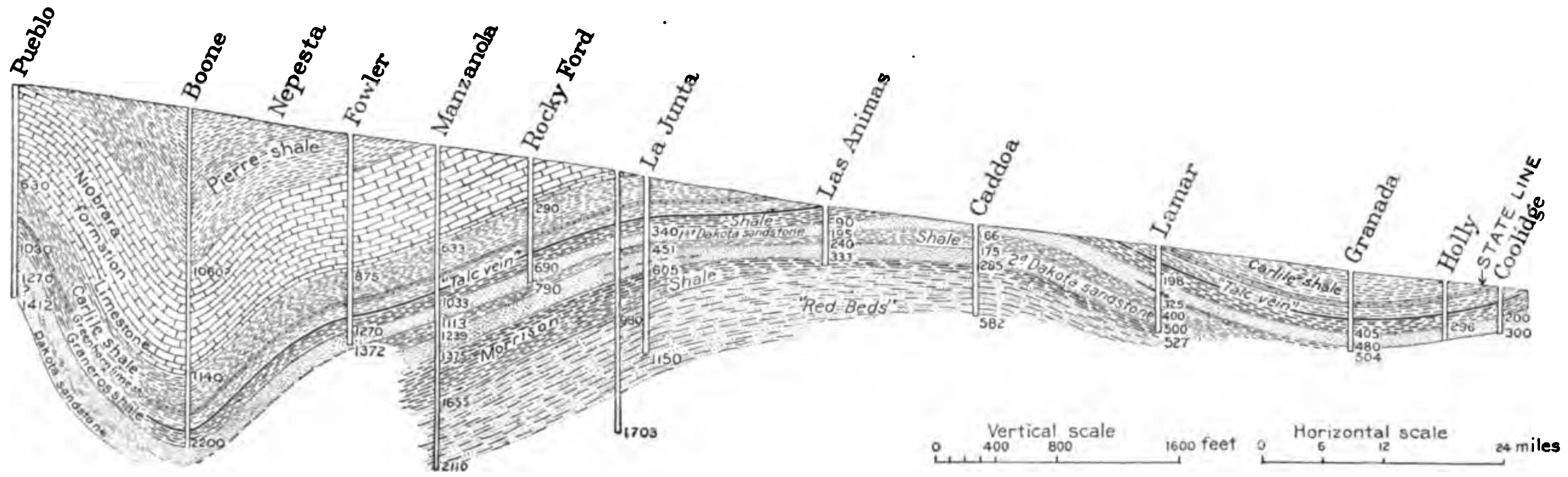
In the thick series of sedimentary rocks underlying southeastern Colorado are several deposits which contain water. The principal water-bearing formation is the "Dakota" sandstone, but waters also occur extensively in the alluvial deposits along the valleys, in the sands and gravels mantling parts of the upland east of the mountains, and in the sandstones of the Fox Hills, Laramie, and overlying formations. Smaller amounts, mostly of bad quality, occur in the "Red Beds."

### "DAKOTA" SANDSTONE WATERS.

#### GENERAL CONDITIONS.

Throughout its wide extent in the Great Plains region the "Dakota" and associated sandstones contain water, usually of good quality and under considerable pressure. This water passes into the sandstones in their elevated outcrop zone along the foot of the mountains and in some of the highlands to the south, and flows slowly eastward through the permeable sandstone, in most cases finally escaping in springs in the areas of low-level outcrop eastward. In the greater part of their area the sandstones lie beneath a mass of impervious shales, which in central-eastern Colorado attain a thickness of several thousand feet. The general structural relations of the formation are shown in detail in the cross sections of Pl. VII.

As the waters pass underground in high areas they have considerable pressure, or "head," under the impermeable strata in the lower lands. In parts of eastern Colorado pressures of 20 to 60 pounds are sometimes presented, which can be explained only by the hydrostatic influence of a column of water extending to a high altitude in the region west. If it were not for the outflow of the water to the east and south the initial head which the waters derive from the high altitude of the intake zone would continue under the entire region, but owing to this leakage the head is not maintained, and there is a gradual diminution to the east, known as



SECTION SHOWING RELATIONS OF WELLS IN ARKANSAS VALLEY FROM PUEBLO TO COOLIDGE.

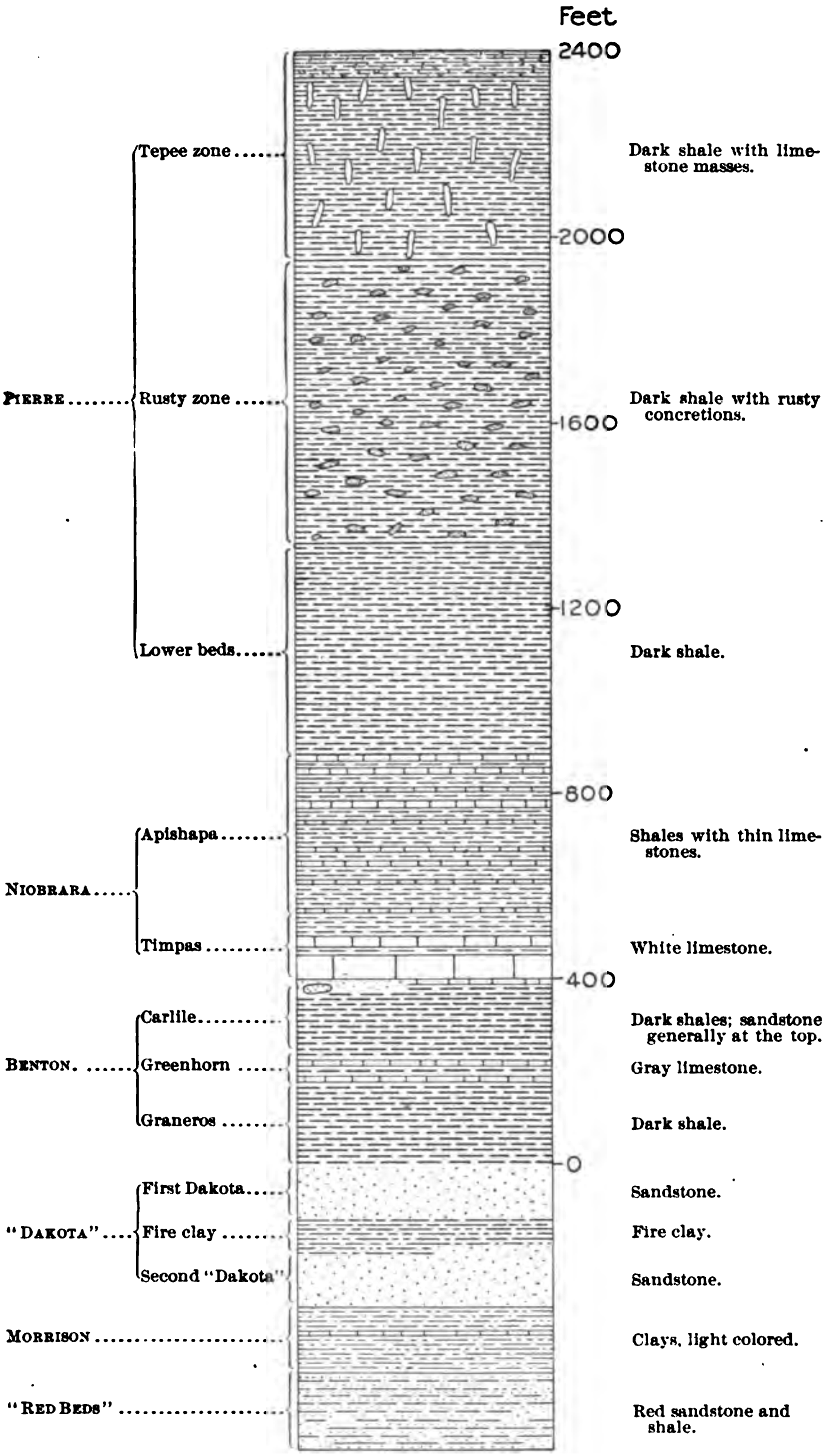


FIG. 1.—General section showing thickness of strata overlying the "Dakota" sandstone in the Arkansas Valley.

"hydrostatic grade," a slope sustained by the friction of the water in its passage through the strata. In fig. 2 is shown a simple apparatus which illustrates the general conditions.

Another factor which undoubtedly somewhat influences the hydrostatic grade in the Great Plains region is a certain but unknown amount of general leakage through the so-called impermeable strata, all of which permit the passage of an appreciable proportion of water, especially when under great pressure. From the altitudes of outcrops of this sandstone and pressures observed in many wells the lines in Pl. XXVIII have been constructed to indicate the observed and probable head of the artesian waters. In areas of flow the pressure in pounds at any point may be ascertained by subtracting the altitude of the land from the altitude of head and dividing by 2.3 (the height in feet of a column of water 1 inch square weighing 1 pound). In areas too high for flow the depth to the point to which the water may be expected to rise may be found by subtracting the altitude of head from the altitude of the land. The latter is shown by the brown lines in Pls. VI and XXV.

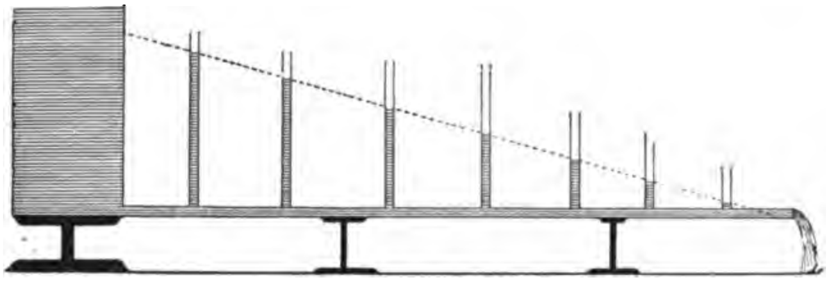


FIG. 2.—Diagram of apparatus for illustrating the declivity of head of liquids flowing from a reservoir. The shaded portions represent water.

## FLOWING WELLS.

*Rocky Ford.*—Nearly all of the flowing wells in the Arkansas Valley derive their water from the "Dakota" sandstone. There are several artesian wells at Rocky Ford which furnish large supplies of excellent water under considerable pressure. The depths vary from 767 to 1,033 feet. Wells Nos. 1 and 2 have a diameter of 7⅝ inches and a flow of over 100 gallons per minute, with sufficient head to rise 80 feet or more above the surface. One of these is shown in Pl. XXIV, *B*. The materials penetrated by these wells are indicated in the following record:

*Record of artesian well at Rocky Ford, Colo.*

| | Feet. |
|---|---|
| Surface materials | 0- 40 |
| Shale | 40-250 |
| Limestone with salty water at its top | 250-290 |
| Shale | 290-605 |
| "Talc vein" | 605-608 |
| Shale | 608-690 |
| First sandstone (Dakota) with a flow of soft water | 690-790 |

These wells begin in the lower part of the Apishapa formation, pass through the characteristic limestone bed at the base of the Timpas formation from 250 to

290 feet, and penetrate 400 feet of the Benton formation. The latter contains the characteristic 3-foot bed of "talc" 100 feet above the top of the "Dakota" sandstone.

An 845-foot well at Wyckoff Park, near Rocky Ford, has a 4-inch bore and a flow of 115 gallons a minute.

The well of the American Beet Sugar Company, sunk by C. H. McVay in 1901, had the following record:

*Record of artesian well of sugar company at Rocky Ford, Colo.*

| | Feet. |
|---|---|
| Surface materials | 0- 30 |
| Gray shale | 30-265 |
| Limestone | 265-312 |
| Black shale, with salt water at 382 feet | 312-700 |
| "Dakota" sandstone | 700-806⅓ |

At 793 feet this boring yielded a 50-gallon flow, which increased to 80 gallons at the bottom.

*Manzanola.*—At Manzanola there is an artesian well which was sunk by the town company. Its depth is 1,113 feet, with a diameter of 7⅝ inches, and it yields 35 to 40 gallons a minute under a pressure of about 55 pounds. The materials penetrated by this well are as follows:

*Record of first artesian well at Manzanola, Colo.*

| | Feet. |
|---|---|
| Surface materials | 0- 38 |
| Shale | 38- 598 |
| Limestone | 598- 633 |
| Shale | 633- 933 |
| "Talc vein" | 933- 936 |
| Shale | 936-1,033 |
| First sandstone (Dakota) | 1,033-1,113 |

The record shows beds of the Apishapa formation, with the typical Timpas limestone at a depth of 598 to 633 feet, underlain by 400 feet of the Benton group. The latter contains the very distinct bed of hard shale at 933 to 936 feet which the well drillers designate the "talc vein," and have recognized in many borings in the Arkansas Valley.

In 1903 a well was sunk at Manzanola for the purpose of testing the formations below the "Red Beds" for oil and gas. A depth of 2,110 feet was attained without satisfactory results. The pipe has been pulled and the well abandoned. The following record has been given:

*Record of deep boring at Manzanola, Colo.*

| | Feet. |
|---|---|
| Loam | 0- 50 |
| Limestone and shales (Niobrara and Benton groups) | 50-1,050 |
| Sandstone; first "Dakota" artesian flow, 50 gallons | 1,050-1,139 |
| Shales | 1,139-1,239 |
| Sandstone; second "Dakota" artesian flow, 10 gallons | 1,239-1,375 |
| Gray clays (Morrison formation) | 1,375-1,655 |
| "Red Beds," with several water-bearing strata | 1,655-2,110 |

The water in the "Red Beds" was too impure for use, and had only pressure enough to rise to 700 feet below the surface.

*Fowler.*—The first flowing well below Pueblo is about 2 miles east of Fowler, on the Atchison, Topeka and Santa Fe Railway. It has a depth of 1,372 feet, at which it obtains a flow of soft water from the upper sandstone of the "Dakota" at the rate of about one-half gallon a minute. The record of this well is as follows:

*Record of artesian well near Fowler, Colo.*

| | Feet. |
|---|---|
| Surface materials | 0- 40 |
| Shale | 40- 825 |
| Limestone | 825- 875 |
| Shale | 875-1,270 |
| First "Dakota" sandstone | 1,270-1,372 |

This boring begins on the Pierre shale, passes through the Apishapa and Timpas formations of the Niobrara, the limestone at 825 to 875 feet being the characteristic bed at the base of the Timpas, and penetrates 395 feet of the Benton formation to the top of the "Dakota" sandstone.

*La Junta.*—In this town there are several wells, formerly flowing, which yield soft water that is extensively used by the railroad company and in part for municipal supply. The principal supply is in the second bed of sandstone of the "Dakota" formation, which is entered at a depth of 555 feet. Most of the wells are between 405 and 439 feet deep. A boring by the railroad company passed through both sandstones of the "Dakota" formation and the underlying shales and sandstone into the "Red Beds," which it penetrated at 1,050 to 1,150 feet. The record of this boring is as follows:

*Record of deep boring at La Junta, Colo.*

| | Feet. |
|---|---|
| Surface materials | 0- 37 |
| Gravel | 37- 48 |
| Shale | 48- 230 |
| "Talc" | 230- 235 |
| Shale and light shale | 235- 340 |
| "Dakota" sandstone, soft water | 340- 423 |
| Black shale | 423- 451 |
| Gray sandstone | 451- 545 |
| Black shale | 545- 555 |
| Sandstone; soft water, flows | 555- 605 |
| Shale | 605- 950 |
| Sandstone; water, no flow | 950-1,050 |
| Red and variegated shale | 1,050-1,150 |

This well was plugged at 700 feet and obtains its principal supply of water from the second bed of sandstone in the "Dakota" formation at 550 to 605 feet. The original flow at 420 feet was 35 gallons a minute, but vigorous pumping has lowered the water level many feet and the water is now forced out by air lift. The wells at La Junta begin in the Timpas formation, but soon pass into the Benton shale, reaching the characteristic "talc vein" at 230 feet and the top of the "Dakota" formation at 340 feet. This formation presents an alternation of heavy beds of sandstone with intercalated shales, and from the record above given may extend to

*A.* ARTESIAN WELL ON RIDGE SOUTH OF LA JUNTA, COLO.

Depth 750 feet to Dakota sandstone. Not flowing at present.

*B.* FLOWING WELL AT ROCKY FORD, COLO.

Flows from a depth of 790 feet from Dakota sandstone.

a depth of 605 feet. The underlying shales and sandy beds are those which outcrop on Purgatory River, 25 miles south of La Junta, lying on the sandstones and shales of the "Red Beds," which were entered at a depth of 980 feet in the deep boring near La Junta.

Two other wells of the railroad company are 420 and 439 feet deep and are pumped by air lift. A well in the McNeen brickyard, with a depth of 405 feet, obtained a small flow at 395 feet, which increased to 8 gallons a minute at 405 feet. Its diameter is 4½ inches. The well at the flouring mill in La Junta is 425 feet deep and flowed 30 to 45 gallons a minute until other wells in the neighborhood were pumped, when the flow ceased. It is now pumped at the rate of 30 gallons a minute, but this is not its full capacity. An analysis of the water is given on pages 80, 81.

A well on the hill in the southern part of the town is about 150 feet above the railroad depot, and its depth is 750 (or 766) feet. When completed, it flowed 25 gallons a minute. Now the water rises only to the surface, owing to partial filling with sand and possibly to a general reduction of the water level in the vicinity by the several wells near the depot. A view of this well is given in Pl. XXIV, *A*.

In 1902 a company was organized to sink a deep well 2½ miles south of La Junta to test the "Red Beds" and their underlying formations for gas or oil. A depth of 1,703 feet was reached without obtaining either of these products. Although a number of beds of limestone were penetrated in the lower portion of the boring, it is probable that they are a part of the "Red Beds" series. The following record has been supplied:

*Record of deep boring south of La Junta, Colo.*

| | Feet. |
|---|---|
| Soft gray limestone | 0- 50 |
| Rusty limestone at base of Niobrara | 50- 60 |
| Dark shales of Benton group | 60- 440 |
| Soft sandstone with artesian flow; first "Dakota" | 440- 504 |
| Shales | 504- 584 |
| Soft sandstone; artesian flow; second "Dakota" | 584- 700 |
| Gray and greenish-gray shales with water at 820 to 120 and 860 to 100 feet (Morrison formation) | 700- 980 |
| "Red Beds" with water at intervals which rose to within 200 feet of the surface | 980-1,703 |

Some samples forwarded to Washington are as follows:

*Samples of borings from La Junta, Colo.*

| | Feet. |
|---|---|
| Sand and fine-grained sandstone of gray color, with some limestone layers and reddish sandstone | 1,230-1,290 |
| Red shale, with some limestone layers | 1,300-1,500 |
| Red shale, with some limestone fragments | 1,535 |
| White sand | 1,600 |
| Red shale, with some limestone fragments | 1,612 |
| Gray limestone and red shale | 1,660 |
| Red shale and gray limestone | 1,703 |

The Lenox well, in SE. ¼ sec. 2, T. 24 S., R. 56 W., 5 miles west of La Junta, has a depth of 740 feet, a diameter of 7⅝ inches, and yields a flow of 12 gallons a minute. The well began in Timpas limestone, 40 feet above its base, passed through 400 feet of Carlile, Greenhorn, and Graneros beds to the top of the "Dakota" sandstone at 440 feet and penetrated the two sandstones of the "Dakota" for 300 feet. In the northeast quarter of the same section, on J. E. Gauger's ranch, there is a similar well flowing 15 gallons a minute. According to Mr. McVay, the driller, the beds are at slightly lower levels, indicating a dip of 27 feet to the mile in that direction.

*Holbrook*.—At this place, which is 9 miles due north of La Junta, in SE. ¼ sec. 27, T. 22 S., R. 55 W., there is a well 661 feet deep, which flows about 100 gallons a minute. The head of the water is sufficient to raise it 80 feet, or probably much more, above the surface, and the flow is about 50 gallons a minute from a 3-inch pipe extending to the bottom. The water is soft. No record was obtainable, but it is stated that the boring passed through 155 feet of limestone, 385 feet of Benton shale with some limestone at a depth of 350 feet, and penetrated 110 feet into the "Dakota" sandstone. In the next township east are two shallower wells which have flows from the sandstone.

*Timpas*.—The following report of the well at this place has been furnished:

*Record of boring at Timpas, Colo.*

| | Feet. |
|---|---|
| Loam | 0- 37 |
| Dry gravel | 37- 40 |
| Shale | 40- 85 |
| Limestone (basal Timpas), some water | 85-137 |
| Shale, with "talc vein" at 440 to 443 feet=398 feet of Benton | 137-538 |
| Sandstone ("Dakota"); poor water at 544 feet, rising to 50 feet; 2-gallon flow at 570 feet | 538-580 |
| Shale | 580-605 |
| Sandstone; poor water | 605-650 |
| Shale | 650-656 |
| Gray sandstone | 656-716 |
| Sandstone ("Dakota"); 20-gallon flow at 755 feet | 716-790 |
| Red shale (Morrison) | 790-795 |

The water which flowed at 755 feet was too highly mineralized to be usable in boilers, so that the boring is regarded as a failure. The water flowed into a tank 27 feet above the ground.

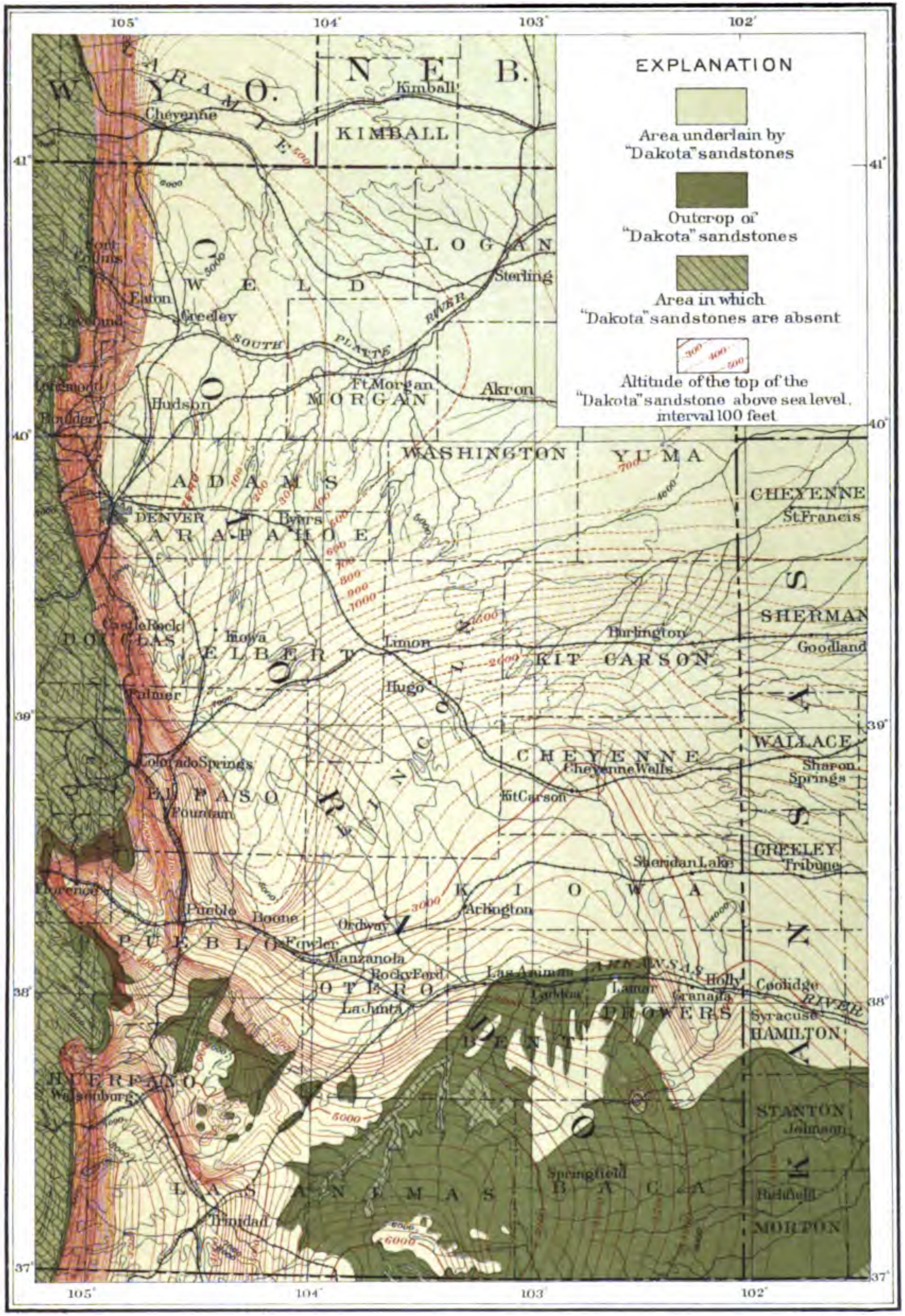
*Ayer*.—This is a siding on the Atchison, Topeka and Santa Fe Railway, 6 miles southwest of Timpas, and the record of the well is as follows:

*Record of boring at Ayer, Otero County, Colo.*

| | Feet. |
|---|---|
| Surface material | 0- 40 |
| Gravel | 40- 43 |
| Gray limestone | 43- 80 |
| Black shale, with "talc vein" 147 to 150 feet | 80-249 |
| Sandstone (Dakota); soft water | 249-272 |
| Shale | 272-280 |
| Gray sandstone; dry | 280-287 |
| Black shale | 287-293 |
| Sandstone; poor water; 25-gallon flow near bottom; 3-gallon flow at 311 feet | 293-343 |

The water is of unsatisfactory quality, containing 18 grains of sulphate of lime to the gallon.

*Bloom (Iron Springs)*.—The boring at this place, sunk for the Santa Fe Railway, had a depth of 1,162 feet and yielded a flow of 5 gallons a minute, with a pressure sufficient to raise it 50 feet or more above the surface, but it was abandoned, as the water was too hard for use in locomotives. The following record is furnished:



A. Hoen & Co. Baltimore

MAP SHOWING STRUCTURE OF "DAKOTA" SANDSTONE IN EASTERN COLORADO

BY N. H. DARTON

1905

Scale

20 10 0 20 40 60 miles

Black contours have 1000-foot intervals; broken lines hypothetical

*Record of boring at [illegible]n siding, Otero County, Colo.*

| | Feet. |
|---|---|
| Clay | 0- 25 |
| Gravel | 25- 31 |
| Shale, with bad water at 76 feet | 31- 87 |
| Gray shale | 87- 154 |
| Gray sandstone | 154- 168 |
| Black shale | 168- 170 |
| Sandstone, brown above; poor water | 170- 229 |
| Shale | 229- 233 |
| Sandstone; 5-gallon flow of water at 240 feet | 233- 244 |
| Hard sandstone | 244- 255 |
| Sandstone; second water at top, first flows 3 to 4 gallons; another flow at 385 feet | 255- 400 |
| Red shale (Morrison) | 400- 450 |
| White sandstone (Morrison) | 450- 455 |
| Red shale | 455- 475 |
| Red sandstone | 475- 575 |
| Light-gray shale | 575- 695 |
| Light-brown sandstone | 695- 815 |
| Dark-red sandstone | 815- 880 |
| Red sandstone | 880- 965 |
| Red shale | 965- 985 |
| Red sandstone | 985- 995 |
| "Marble" | 995-1,000 |
| Red shale | 1,000-1,007 |
| Red sandstone; water rose 450 feet; quality bad | 1,007-1,020 |
| White "limestone" | 1,020-1,025 |
| Red sandstone | 1,025-1,085 |
| "Limestone" | 1,085-1,087 |
| Red sandstone | 1,087-1,125 |
| "Limestone" | 1,125-1,128 |
| Pink sandstone; water rose 80 feet | 1,128-1,133 |
| Red sandstone | 1,133-1,140 |
| Red shale | 1,140-1,145 |
| White sandstone; water rose 350 feet | 1,145-1,155 |
| Red shale | 1,155-1,162 |

The boring begins near the base of the Graneros shale of the Benton group and passes through various members of the "Dakota" sandstone series into the "Red Beds." It was located on the axis of the anticline extending from the south. It is difficult to understand why a large supply of water was not obtained from the various sandstones which were reported.

*Las Animas.*—The railroad well at Las Animas is relatively shallow, obtaining a 20-gallon flow of excellent water from the second sandstone in the "Dakota" formation at a depth of 330 feet. The following record is reported:

*Record of artesian well at Las Animas, Colo.*

| | Feet. |
|---|---|
| Surface materials | 0- 36 |
| Shale | 36- 90 |
| Sandstone; water at a depth of 90 feet, rising to −10 feet | 90-195 |
| Shale | 195-240 |
| Sandstone; flow at 330 feet | 240-333 |
| Shale | 333-360 |

This well begins in the lower part of the Benton shale and reaches the "Dakota" sandstone at a depth of 90 feet, as this formation rises rapidly east of La Junta. The second bed of sandstone in the "Dakota" formation begins at 230 feet, with the usual intervening mass of shale. (See Pl. XXIII.) Other wells in Las Animas have depths of 250 and 267 feet and flow 17 and 5 gallons, respectively. A well sunk in 1904 on the Cooper place, a mile north of Las Animas, has a depth of 316 feet and a flow of 10 gallons a minute from a depth of 285 feet. It is cased with 5⅝-inch tubing. The pressure is sufficient, it is said, to lift the water 20 feet above the surface. The following record has been furnished by John Baugh, the driller:

*Record of Cooper well, 1 mile north of Las Animas, Colo.*

| | Feet. |
|---|---|
| Surface materials | 0– 10 |
| Sand, with water | 10– 30 |
| Black, sandy shale | 30– 60 |
| Black shale | 60– 70 |
| Sandstone (Dakota), with water to —6 feet | 70–170 |
| Shale, with sandstone layers | 170–266 |
| Sandstone (second "Dakota"), with main flow at 285 feet | 266–316 |

Twelve miles northeast of Las Animas is the well which was sunk in 1881 by the Government under direction of the Department of Agriculture. It was known as well No. 1, and is located 7 miles northeast of Fort Lyon. It had a depth of 815 feet, but obtained only a small amount of water from a depth of 430 feet, which flowed at the surface at a rate reported by some persons as 2 gallons a minute, and by others as only 3 gallons an hour. The head was stated to be just sufficient to raise the water 10 feet above the surface of the ground. This boring cost $18,353; the record is as follows:

*Record of boring at Fort Lyon, Colo.*

| | Feet. |
|---|---|
| Sand, gravel, and quicksand | 0– 74 |
| Soft, blue clay | 74– 80 |
| Blue shale | 80– 86 |
| Gray sandstone | 86–116 |
| Dark shales | 116–120 |
| Streaked sandstone | 120–140 |
| Gray, clean grit | 140–150 |
| Black, sandy shale | 150–180 |
| Mottled, gray sandstone | 180–190 |
| Mica sandstone | 190–200 |
| Mixed sandy shale, light, very soft | 200–225 |
| Mixed sandy shale, dark, very soft | 225–250 |
| Black, variegated shale, very soft | 250–275 |
| Mottled purple shale, soft | 275–300 |
| Gray shale, soft | 300–320 |
| Mottled shales, soft | 320–340 |
| Black shale, soft | 340–344 |
| Gray sandstone | 344–355 |
| Coarse sandstone | 355–368 |
| Gray sandstone | 368–382 |
| Greenish clay | 382–386 |
| Marl | 386–396 |
| Green and red sandstone, soft | 396–439 |

| | Feet. |
|---|---|
| Dark-red shale | 439–445 |
| Rusty gray sandstone | 445–450 |
| Green shale | 450–460 |
| Green and red shale, soft | 460–500 |
| Gray sandstone | 500–520 |
| Compact gray shale | 520–550 |
| Hard shales | 550–570 |
| Fine, red sandstone | 570–590 |
| Coarse, red sandstone | 590–630 |
| Hard, red sandstone; some gypsum | 630–650 |
| Spotted sandstone | 650–662 |
| Mixed sandstones | 662–703 |
| Red sandstone, massive | 703–751 |
| Soft, red sandstone | 751–783 |
| Spotted red sandstone | 783–815 |

The Marlaman well on Horse Creek, 12 miles northwest of Las Animas, has a depth of 493 feet, and a 7-gallon flow from the second "Dakota" sandstone. The following record was furnished:

*Record of artesian well, 12 miles northwest of Las Animas.*

| | Feet. |
|---|---|
| Surface materials | 0– 30 |
| Limestone and shale | 30–230 |
| Dakota sandstone, small flow | 230–330 |
| Shale and sandstone | 330–443 |
| Second "Dakota" sandstone | 443–493 |

*Plum Creek.*—At the Blackwell ranch, on Plum Creek, about 20 miles south of Granada, there is a small artesian well which obtains its flow from the "Dakota" sandstone at a depth of 155⅓ feet. It is in sec. 1, T. 26 S., R. 44 W. The head was found more than sufficient to raise the water to the top of the tubing, 46 feet above the ground. The volume is 18 gallons or more a minute. This well is important as indicating that artesian waters may be expected in the central and east-central portions of the county, at some distance south of the Arkansas Valley. Much of this region is occupied by the Greenhorn limestone in the middle of the Benton group, so that ordinarily about 250 feet of shales would have to be passed through to reach the top of the "Dakota" sandstone, and this formation penetrated for a hundred feet or more to obtain a water supply.

*Pueblo.*—The first deep well in the Arkansas Valley was a boring for petroleum made at South Pueblo in 1879. At a depth of 1,166 feet a flow of mineral water was obtained, amounting to about 100 gallons a minute. The boring was continued to a depth of 1,412 feet, and was cased to a depth of 900 feet with 6-inch casing. The well has continued to flow with nearly its original volume and a pressure of 60 pounds to the square inch. The water is not suitable for domestic use, but is the basis for the Clark mineral-spring resort, where it is employed for bathing and medicinal purposes. The record of the well is as follows:

*Record of deep well at Clark's mineral spring, Pueblo, Colo.*

| | Feet. |
|---|---|
| Soil and gravel | 0- 34 |
| Blue shale | 34- 58 |
| Black shale | 58- 630 |
| Sand rock, white below | 630- 690 |
| Black shale | 690- 700 |
| Soft, coarse sand rock | 700- 735 |
| Black shale | 735- 900 |
| Sand rock | 900- 940 |
| Black shale | 940-1,030 |
| Sand rock | 1,030-1,045 |
| Soft black shale | 1,045-1,148 |
| Sand rock with flow of water | 1,148-1,180 |
| Black shale | 1,180-1,195 |
| Coarse sand rock | 1,195-1,230 |
| Purple shale | 1,230-1,240 |
| Sand rock | 1,240-1,270 |
| Not given | 1,270-1,400 |
| Purple shale | 1,400 |

The Colorado Coal and Iron Company has a well on the mesa south of and about 100 feet higher than the Clark well. The depth is 1,260 feet, and the flow of 20 to 25 gallons a minute is not utilized. An analysis of this water is given on pp. 80–81. Another well at Mineral Park in the same vicinity obtains a small flow from a depth reported to be 1,150 feet. At the Fariss House, north of the river, in Pueblo, a well said to be 1,400 feet deep flows 13 gallons a minute and has a pressure of 60 pounds to the square inch. An analysis of this water is given on pp. 80–81.

At the Grand Hotel in Pueblo is a well 1,219 feet deep and 4½ inches in diameter which has a flow of about 20 gallons a minute of mineral water under a pressure of 50 pounds to the square inch. At 1,050 feet there was a flow of fresh water under a pressure of 15 pounds. An analysis of the water is given on pp. 80–81. On Columbia Heights, a suburb of Pueblo, there is a 789-foot well which found a small flow at 516 feet, and a second flow at 779 feet—in all about 8 gallons a minute.

*Record of well in sec. 9, T. 21 S., R. 65 W., Columbia Heights, Pueblo, Colo.*

| | Feet. |
|---|---|
| Soil on gravel | 0- 31 |
| Shale | 31- 90 |
| Limestone | 90-105 |
| Black slate | 105-516 |
| Sandstone, with water | 516-616 |
| Black slate | 616-779 |
| Sandstone, second flow | 779-789 |

In the adjoining section 17 is a well sunk by C. H. Small, which in 1888 had a depth of 772 feet and a small flow. It was deepened later to a second flow. The water is similar to that of other wells in the Pueblo region, containing a good deal of mineral matter. The following record is given:

*Record of artesian well of C. H. Small, Pueblo, Colo.*

| | Feet. |
|---|---|
| Black soil | 0-12 |
| Blue shale | 12-72 |
| Limestone | 72-82 |

| | Feet. |
|---|---|
| Black shale | 82-413 |
| White sandstone | 413-575 |
| Red rock | 575-760 |
| Gray sandstone | 760-772 |

On North Pueblo Heights a well was sunk by a suburban company to a depth of 1,820 feet, finding small flows at 1,200 and 1,820 feet. This well is in sec. 12, T. 20 S., R. 65 W. A flow of 1½ gallons was reported in 1889. All the Pueblo wells draw their water supply from either the upper or the lower sandstone of the "Dakota" formation, but the water is too much mineralized to be of general use. There was formerly a well known as McLane's, 9 miles west of Pueblo and 4 miles south of Arkansas River, on Boggs Flat. It was sunk for oil, but none was found. Water was reported at several horizons, but no depths were stated.

A well on the south side of the river 10 miles west of Pueblo is 795 feet deep and has a 30-gallon flow. Sandstone was entered at 535 feet. The water contains 110 grains of solid matter per gallon.

*Florence.*—Some of the oil wells in the vicinity of Florence encounter more or less water at various depths down to about 1,150 feet. The water is strongly mineralized and often is in large volume. A typical record is reported as follows:

*Record of well in sec. 23, T. 19 S., R. 69 W., near Florence, Colo.*

| | Feet. |
|---|---|
| Surface materials | 0- 20 |
| Shale and sandy shale; flow of water | 260- 280 |
| Shale, with layers of limestone | 280- 650 |
| Limestone | 650- 695 |
| Sandstone | 695- 699 |
| White sandstone, second flow | 699- 722 |
| Shales, limestone, and sandstone; very large flow | 722-1,130 |
| Shales and sandstone | 1,300-1,400 |
| Soft shale | 1,400-1,600 |

In 1905 an artesian well was completed 6 miles north of Florence, which is reported to have a flow of 360 gallons a minute from a 5⅝-inch casing. It is located in the SW. ¼ sec. 26, T. 18 S., R. 69 W., and has a depth of 1,230 feet. The water rises 6 feet above the surface and has sufficient head to rise 80 feet or more. The temperature of flow is 87°. Water was found at depths of 230 to 235, 300 to 345, and 815 to 900 feet, besides the main flow at 1,210 feet. The record is as follows:

*Record of well in SW. ¼ sec. 26, T. 18 S. R. 69 W.*

| | Feet. |
|---|---|
| Sandy loam, reddish | 0- 13 |
| Conglomerate | 13- 18 |
| Light-blue clay (Pierre) | 18- 210 |
| Light-blue lime | 210- 250 |
| Light-colored sand | 250- 255 |
| Shale and limestone, alternating | 255- 780 |
| Light-colored limestone | 780- 810 |
| Light-colored sandstone | 810- 825 |
| Shale, with hard layers, some limestone | 825-1,025 |
| Drab shale | 1,025-1,195 |
| Sandstone, with hard layers | 1,195-1,210 |
| "Dakota" sandstone | 1,210-1,230 |

*Canyon.*—Three miles east of Canyon there is a flowing well 900 feet deep which appears to derive its flow from a sandy member in the Pierre shale. Another well 5 miles south, 360 feet deep, has a large flow from the same source, or the basal Laramie sandstone. A new well at the Sanitarium, 3 miles northeast of Canyon, has a depth of 1,670 feet. It is 6 inches in diameter and yields a 300-gallon flow under a pressure of about 30 pounds, probably from the "Dakota" sandstone.

*Portland.*—This well is 10 miles south of Portland, on a branch of Ritchie Creek, near the south margin of Fremont County. It flows about 600 gallons a minute from a 6-inch casing and has a depth of 1,135 feet. It begins in the upper beds of the Apishapa formation, at an altitude of about 5,550 feet, but no reliable record could be obtained of the beds penetrated. Probably the Niobrara group has a thickness of about 650 feet and the Benton about 415 feet, for it is stated that the "Dakota" sandstone was entered at a depth of 1,065 feet. The water contains some iron and other salts, but appears to be satisfactory for domestic use and irrigation. Two views of this well are given in Pl. XXVII, which also show the deep hole washed out by the water that escapes along the side of the casing. This well indicates that wide areas of flat lands, extending east and north for many miles, are within reach of flowing waters which may prove to be valuable in reclaiming the land. Much of this area has the fertile, limy soils of the Apishapa formation.

*Chandler.*—A short distance west of Chandler, which lies south of the city of Canyon, there is a flowing well 1,075 feet deep sunk in a syncline near the foot of the Wet Mountain Range. Its flow is derived from the "Dakota" sandstone and is reported to be 80 to 100 gallons a minute. The water is tepid, has a decided iron and sulphate taste, and deposits a yellowish-red precipitate on standing. Two other wells in the same vicinity yield flows from depths of 487 and 364 feet.

*St. Mary.*—A 1,670-foot well just east of St. Mary obtains a strong flow from Dakota sandstone. The water is "alkaline" and is not used.

### NONFLOWING DEEP WELLS.

*Ordway.*—At Ordway, on the Missouri Pacific Railroad, several wells have been sunk which have not succeeded in obtaining a flow. The "Dakota" sandstone was penetrated by these and was found to contain an abundance of water, which, however, would not rise higher than to 80 or 90 feet below the surface. The materials reported in one of the borings, which has a depth of 1,508 feet, are as follows:

*Record of boring at Ordway, Colo.*

| | Feet. |
|---|---|
| Surface materials | 0- 42 |
| Black shale | 42- 60 |
| Blue and gray shale | 60- 90 |
| Shale and shells | 90-116 |
| Blue shale | 116-145 |
| Black shale | 145-185 |
| Sandstone | 185-245 |
| Black shale | 245-270 |
| Gray shale | 270-345 |
| Limestone, soft | 345-410 |
| Gray shale, some limestone | 410-473 |

*A*

*B*

ARTESIAN WELL 10 MILES SOUTH OF PORTLAND, COLO.

Depth about 1,000 feet; flow about 700 gallons a minute from Dakota sandstone.

| | Feet. |
|---|---|
| Gray shale, darker below | 473– 580 |
| Black shale | 580– 650 |
| Gray shale | 650– 700 |
| Shale with shells | 700– 710 |
| Shale | 710– 765 |
| Brown shale | 765– 785 |
| Light-gray shale | 785– 800 |
| Brown shale | 800– 825 |
| Shale and limestone layers | 825– 845 |
| Black shale | 845– 855 |
| Shale with limestone layers | 855– 925 |
| Limestone and shale | 925– 960 |
| Limestone | 960–1,010 |
| Black shale | 1,010–1,325 |
| "Talc" | 1,325–1,327 |
| Black shale | 1,327–1,410 |
| Sandstone (Dakota) containing some water | 1,410–1,500 |

This boring apparently began in the Pierre shale, passed through the basal limestone of the Timpas formation at 960 to 1,010 feet, but either did not penetrate sufficiently far into the "Dakota" sandstone to obtain flowing water or more likely the altitude of Ordway is too high to afford a flow.

*Sugar City.*—The boring at Sugar City reached a depth of 1,308 feet, but did not obtain a flow. This well is reported to have entered the "Dakota" sandstone at a depth of 1,230 feet.

*Arlington.*—A well has been sunk in sec. 13, T. 21 S., R. 54 W., in the northeast corner of Otero County, 10 miles southwest of Arlington and 18 miles due east of Ordway. It has a depth of 715 feet, but, although it reached the "Dakota" sandstone, the head was not sufficient to afford a flow, the water level coming only to 60 feet of the surface. The supply appears to be ample, for the well was pumped 20 gallons a minute. The following record is given:

*Record of well in sec. 13, T. 21 S., R. 54 W., 18 miles due east of Ordway, Otero County, Colo.*

| | Feet. |
|---|---|
| Sand and clay | 0– 40 |
| Blue shale | 40–180 |
| Sandstone | 180–187 |
| Gray shale | 187–227 |
| Limestone | 227–267 |
| Brown shale | 267–372 |
| Limestone | 372–377 |
| Sandy shale | 377–432 |
| Slate | 432–477 |
| Brown shale | 477–584 |
| Slate | 584–594 |
| Black sandy shale | 594–688 |
| Gray sandstone | 688–703 |
| Water-bearing sandstone | 703–715 |

*Las Animas.*—A well was sunk in 1903 in sec. 36, T. 21 S., R. 52 W., 6 miles west of the Government well, to a depth of 720 feet. A satisfactory supply of water was found in sandstone at 452 to 474 feet, but, as it rose only to within 300 feet of the surface the well is regarded as a failure. The following record was furnished by the owner, Mr. O. G. Scott:

*Record of well 8 miles north-northeast of Las Animas, Colo.*

| | Feet. |
|---|---|
| Loam and sandstone | 0- 25 |
| Dark shale | 25-452 |
| Dakota sandstone; water to —300 feet | 452-475 |
| Dry sandstone | 475-596 |
| Dark shale | 596-656 |
| Gray shale with "bowlders" (?) | 656-700 |
| "Talc" | 700-710 |
| Gray shale lying on red shale | 710-720 |

This well began at the top of the Carlile formation and passed through the formations of the Benton group to the top of "Dakota" sandstone, at 452 feet. The sandstone is reported to be 144 feet thick and underlain by 124 feet of Morrison shales to the top of the "Red Beds," at a depth of 720 feet.

*Caddoa.*—At this station, which is on the Atchison, Topeka and Santa Fe Railway, on the river bank, a well has been bored to a depth of 582 feet. The upper bed of the "Dakota" sandstone outcrops extensively in this vicinity, and the well reaches the lower part of the lower sandstone of the formation. It is 10 miles southeast of the Government well described on page 58. The water obtained at 285 feet was hard, so that the wells which are now in use obtain their supply from the upper bed at a depth of 70 feet, where the water is relatively soft. The following record is given:

*Record of well at Caddoa, Colo.*

| | Feet. |
|---|---|
| Surface materials | 0- 29 |
| Yellow clay | 29- 33 |
| Sandstone, soft water at 50 feet | 33- 66 |
| Shale | 66-175 |
| Sandstone, hard water | 175-285 |
| Variegated shale, water to —75 feet | 285-300 |
| Sand rock, water to —60 feet | 300-345 |
| Shale | 345-384 |
| White sand rock | 384-425 |
| Red shale and sand | 425-492 |
| White slate | 492-582 |

*Lamar.*—At Lamar there are several wells 226 to 522 feet deep, which furnish water for the railroad and the town. Some of them afford a flow, but the head is very slight. The well at the railroad tank pumps 80 gallons a minute with the pump barrel 200 feet below the surface. Its record is reported as follows:

*Record of well at Lamar, Colo.*

| | Feet. |
|---|---|
| Surface materials | 0- 34 |
| Shale | 34- 72 |
| "Talc vein" | 72- 75 |
| Shale | 75-198 |
| Dakota sandstone; water to —20 feet | 198-265 |
| Shale | 265-270 |

| | Feet. |
|---|---|
| Sandstone; soft water | 270–325 |
| Shale | 325–400 |
| Sandstone | 400–404 |
| Sandy shale | 404–460 |
| Sandstone; soft water, which at 480 feet rises to −60 feet and at 500 feet just flows | 460–500 |
| Variegated shale—red, chocolate, and brown | 500–527 |

The variegated shales in the bottom of the well are probably at the top of the Morrison formation. At the waterworks in Lamar a large supply of water is pumped from the "Dakota" sandstone at a depth of 300 feet, rising to within 28 feet of the surface. The water has the composition stated on page 80.

A well 107 feet deep, in the NE. ¼ sec. 36, T. 24 S., R. 47 W., found a large supply of water in "Dakota" sandstone. Its diameter is 5 inches and one large windmill does not pump it dry. The water is soft, but contains an appreciable amount of salts.

*Granada.*—The railroad well at this place has the following record:

*Record of deep well at Granada, Colo.*

| | Feet. |
|---|---|
| Surface materials; hard water | 0– 36 |
| Shale | 36– 58 |
| Limestone yielding bad water | 58– 60 |
| Shale | 60– 78 |
| Limestone | 78– 80 |
| Gray shale | 80–195 |
| Black shale | 195–323 |
| "Talc vein" | 323–326 |
| Black shale | 326–353 |
| Sandy shale; some soft water | 353–405 |
| Dakota sandstone; soft water | 405–480 |
| Shale | 480–497 |
| White clay | 497–504 |

The original water level in the well was about 25 feet below the surface, but it is pumped down to below 80 feet, yielding about 80 gallons a minute.

The town well at Granada, drilled in 1904, in the center of the town, has a depth of 480 feet, where a large supply of water is obtained. The water is soft and rises to within 30 feet of the surface.

*Amity.*—The well at Amity has a depth of 384 feet, reaching the "Dakota" sandstone at 310 feet. The water rises to within 19 feet of the surface; the supply is very large, and the quality is highly satisfactory. The well is cased with 100 feet of 7½-inch casing through sand and gravel to the first shale, 187 feet of 6¼-inch casing to shut out some very hard water at a depth of 187 feet, and 380 feet of 5-inch casing reaching into the "Dakota" sandstone. In one report it is stated that the top of the "Dakota" sandstone is at 297 feet, consisting of 4 feet of sand lying on shale, and that the second sand with the principal flow was entered at 376 feet and penetrated 8 feet. The head of the water in this well is below the level of Arkansas River.

Three miles north of Amity, in SE. ¼ sec. 25, T. 22 S., R. 43 W., there is a deep well, sunk by the Sugar Beet and Irrigated Land Company in 1902. It is 699 feet deep, 8 to 6 inches in diameter, and yields a large supply of excellent soft water, which rises to within 100 feet of the surface. Some water was found at 300 feet and other depths, but the water utilized is from the bottom of the well. The following record of this well was supplied by the company:

*Record of well 3 miles north of Amity, Colo.*

| | Feet. |
|---|---|
| Gravel and sand | 0- 92 |
| Limestone | 92-132 |
| Dark shale | 132-610 |
| Dakota sandstone | 610-699 |

*Holly.*—At Holly there is a well which reaches the "Dakota" sandstone at 296 feet and obtains a satisfactory supply of excellent water. At the sugar factory, one-half mile west of Holly, a new well 412 feet deep obtains a water supply which rises to within 20 feet of the surface. The diminished depth to the "Dakota" at this place indicates that the strata are rising eastward from Granada, as shown in the section, Pl. XXIII.

*Delhi.*—At a siding on the Santa Fe Railway 8 miles north of Thatcher a well was sunk in 1901-2 by the railway company to a depth of 322 feet. The well draws water from several beds, from 132 feet down to its bottom. The original water level was 50 to 75 feet below the surface, but it has been greatly lowered by pumping. With the cylinder at 152 feet it yields 37 gallons a minute. The following record was furnished:

*Record of well at Delhi, Otero County, Colo.*

| | Feet. |
|---|---|
| Clay | 0- 75 |
| Dark-gray sand | 75-110 |
| Light-gray sand | 110-120 |
| Dark-gray sand, with water at 130 feet | 120-141 |
| Light-gray sand | 141-161 |
| Dark-gray sand | 161-176 |
| Black shale | 176-185 |
| Dark-gray sand | 185-205 |
| Shale | 205-218 |
| White sand | 218-305 |
| Water-bearing beds | 305-322 |

This boring begins near the bottom of the Graneros shale and penetrates nearly to the bottom of the "Dakota" sandstones. The failure of this well to afford a flow is due to outcrop of the sandstones in the depressions west and north.

*Tyrone.*—This is a siding on the Santa Fe Railroad 8 miles south of Thatcher. The well was sunk in 1902 by the railroad company to a depth of 580 feet. It draws its main supply, which pumps 50 gallons a minute, from a depth of 577 feet, with the pumping cylinder at 423 feet. The height to which the water rose originally is not stated. The following record is furnished:

*Record of well at Tyrone, Las Animas County, Colo.*

| | Feet. |
|---|---|
| Loam and clay | 0- 30 |
| Limestone | 30- 70 |
| Black shale with bad sulphur water at 175 feet, rising to —70 feet | 70-345 |
| "Talc vein" | 345-350 |

| | Feet. |
|---|---|
| Black shale | 350–438 |
| Sandstone (first "Dakota"), with water at 458 feet, which rose to about —375 feet | 438–480 |
| Black shale | 480–490 |
| Sandstone (second "Dakota"), main water supply | 490–577 |
| Black shale | 577–580 |

This boring begins in the lower portion of the Timpas formation, passing out of the Timpas limestone at 70 feet and through 368 feet of beds of the Benton group, with characteristic "talc vein" at 345 feet, to the "Dakota" formation at a depth of 438 feet. The low head of the water is due to the low level of "Dakota" sandstone outcrops to the west, north, and east.

*Trinidad.*—Several deep borings have been made in and near Trinidad for gas, oil, and water, but only water has been obtained. One boring southwest of the city is claimed to have reached a depth of 3,000 feet. Two borings in the railroad yards have reached depths in excess of 2,600 feet and obtained water from the "Dakota" sandstone, which lies at a depth of 2,585 feet. One well, reported by the Colorado Southern Railroad Company, has a depth of 2,713 feet; at 2,595 feet an abundant supply of excellent water is obtained, which rises to within 195 feet of the surface. The well begins about 150 feet below the top of the Pierre shale. The following partial record is given:

*Record of railroad well at Trinidad, Colo.*

| | Feet. |
|---|---|
| Loam and gravel | 0– 42 |
| Gray shale, some water from 150 to 250 feet | 42–2,200 |
| Lime shale and black shale with some gas at 2,220 feet | 2,200–2,400 |
| Black shale (Graneros) | 2,400–2,585 |
| "Dakota" sandstones, close and hard | 2,585–2,713 |

*Barela.*—A well sunk by the Colorado Southern Railroad Company at Barela has a depth of 1,340 feet, obtaining water which rises to within 300 feet of the surface, and pumps 30 gallons a minute. The following record has been furnished by the railroad company:

*Record of well at Barela, Las Animas County, Colo.*

| | Feet. |
|---|---|
| Gravel and loam | 0– 27 |
| Gray shale | 27– 680 |
| Limestone (Timpas) | 680– 704 |
| Black shale | 704–1,063 |
| First "Dakota" sandstone | 1,063–1,213 |
| Shale | 1,213– ? |
| Second "Dakota" sandstone | ? –1,323 |
| Red rock | 1,323–1,340 |

This boring began in the Apishapa shales about 100 feet below the top of the formation and passed through the basal Timpas limestone at 704 feet. The Benton group has a thickness of 359 feet, in which the Greenhorn limestone was not reported. The "Dakota" sandstones have a thickness of 260 feet and the underlying "red rock" reported is probably in the Morrison formation. The thickness of shale between the upper and lower sandstones was not given.

*Watervale.*—A well sunk by the Colorado Southern Railroad Company at Watervale, near the southeast corner of Las Animas County, has a depth of 327 feet. "Dakota" sandstone was found under gray shale at a depth of 100 feet and penetrated to 285 feet, where red rocks were entered and bored into for 42 feet. Water, which rose some distance, was obtained in the "Dakota" sandstone.

*Wetmore.*—In Pueblo County, 1½ miles east of Wetmore, a boring for oil reached a depth between 1,300 and 1,400 feet. It penetrated the "Dakota" sandstone for 30 feet. The rock was found to be very hard. Water was encountered, which rose to within 100 feet of the surface, which is a high mesa near the foot of the mountains. This boring is about a mile south of the flowing well described on page 62, but is on land about 450 feet higher. It began in terrace deposits capping Pierre shale.

### UNSUCCESSFUL DEEP BORINGS.

*Cheyenne Wells.*—The well at this place was bored under the direction of the Department of Agriculture more than twenty years ago, by means of an appropriation provided by a special act of Congress. No official data have been obtained regarding its depth, record, and results, except the statement that it was unsuccessful. As considerable gas was encountered in its lower portion, a local company was organized to develop a gas supply by a second boring, which reached a depth of 1,700 feet and was then abandoned, as the gas was found to be of insufficient quantity. Through the kindness of Mr. McLane, of Cheyenne Wells, the following record was obtained:

*Record of boring at Cheyenne Wells, Colo.*

| | Feet. |
|---|---|
| Clay | 0- 30 |
| "Magnesia" | 30- 60 |
| Sandy gravelly clay | 60- 110 |
| White sandy clay | 110- 130 |
| Soft white sand | 130- 145 |
| White sandy clay | 145- 185 |
| Soft white sand | 185- 215 |
| Soft black shale; good water at 257 feet | 215- 534 |
| White sandy shale; gas | 534-1,260 |
| Chalk rock; brackish water | 1,260-1,330 |
| Fine sand | 1,330-1,360 |
| Soft black shale | 1,360-1,460 |
| Soft white sand or limestone | 1,460-1,510 |
| Black shale | 1,510-1,700 |
| (Not given, but thought to be shale) | 1,700-1,770 |

In this boring a large supply of excellent water was obtained at a depth of 257 feet at the base of the Tertiary formations, but it did not rise far in the casing. The record appears to indicate that the Tertiary formations extend to 215 feet, but probably they really extend to 257 or 260 feet, where the black shale begins in the two shallow wells now in use at the railroad tank. The upper shales are undoubtedly Pierre, and the chalk rock at 1,260 to 1,330 is a portion of the Niobrara. The supposed limestone at 1,460 to 1,510 feet is probably the Timpas limestone, at the base of the Niobrara, and if this is the case the boring stopped in the top of the shales not far above the top of the "Dakota" sandstone. It was intended that the Government boring should be continued to 2,000 feet, but with the small-sized casing used in its lower portion the bit could not progress below about 1,770 feet. It is unfortunate that the boring was not sunk to the depth intended, as there were excellent prospects of reaching the "Dakota" sandstone and obtaining water for a pump well. It would thus have thrown most important light on the head of the water and prospects in adjoining regions.

*Kit Carson.*—A well bored at Kit Carson in 1870 by the Kansas Pacific Railroad, which attained a depth stated by various authorities as 1,300, 1,460, and 1,500 feet was also unsuccessful. Doubtless it penetrated practically the same beds as those below 300 feet in the Cheyenne Wells boring.

*Sheridan Lake.*—At Sheridan Lake a local company sunk a well to a depth of 1,280 feet, and found considerable water, but without sufficient head to afford a surface flow. The boring is now abandoned. The lowest water in any appreciable volume was at a depth of 1,200 feet in a dark-colored sandstone, from which it rose to within 40 or 50 feet of the surface. No record is obtainable, but as the boring begins in the upper portion of the Niobrara chalk, doubtless the sandstone at 1,200 feet is "Dakota."

*Hoehne.*—At this station on the Santa Fe Railroad, 9 miles northeast of Trinidad, a boring was made to the depth of 936 feet, but, unfortunately, it was abandoned before it reached the "Dakota" sandstone, which should there be expected at a depth of about 1,100 feet. The boring was begun at the base of the Pierre shale, penetrated the Apishapa and Timpas formations, here about 700 feet thick, and passed low into the Carlile shale. Doubtless it would have found water in the "Dakota" sandstone, and, as the locality is nearly 300 feet lower than Trinidad, it might have obtained a flow. To the north of this place the depth to the "Dakota" beds diminishes as the outcrop zone of the Niobrara formation is crossed, and the sandstone comes to the surface a short distance south of Thatcher.

*Thatcher.*—In 1884 a boring was made at this place to a depth of 920 feet. It began near the top of the "Dakota" sandstone and penetrated several hundred feet into the "Red Beds." Some water was found near the bottom, which rose 300 feet. No record was obtainable, and neither the quality nor the volume of water was stated.

*Troy.*—At a transient settlement by this name, 25 miles north of Watervale, a boring 400 to 500 feet deep was sunk several years ago. It began in "Dakota" sandstone. No record or other information was obtained, except that it was regarded a failure.

*Rouse Junction.*—At Rouse Junction, a station on the Denver and Rio Grande Railroad southeast of Walsenburg, the railroad company made a boring to a depth of 2,058 feet, but did not find an adequate water supply. A small amount of fresh water appeared at 700 and 1,760 feet, and of salt water at 890 feet. These waters rose for some distance, but the greatest height was more than 200 feet below the surface. The following record was furnished by the railroad company:

*Record of well at Rouse Junction, Colo.*

| | Feet. |
|---|---|
| Shale | 20-800 |
| Coarse white sandstone | 800 |
| Black shale; bad water | 850 |
| Hard white sandstone | 870 |
| Hard rock (reported as granite) | 930 |

| | Feet. |
|---|---|
| Hard white sandstone | 940 |
| Black shales | 950 |
| Hard white sandstone | 960 |
| Slate | 1,010 |
| Shale | 1,020 |
| Hard white sandstone and quicksand | 1,030 |
| Hard white sandstone and quicksand | 1,140 |
| Coarse white sand with a little water | 1,150 |
| Coarse red sandstone | 1,160 |
| Coarse green sandstone | 1,190 |
| Pink slate and sand and "granite" | 1,210 |
| Red sand | 1,290 |
| Pink slate | 1,320 |
| Drab sand with shells | 1,350 |
| Fine hard white sand | 1,380 |
| Fine drab sand and white hard clay | 1,390 |
| Red flinty rock | 1,450 |
| Fine gray sand, very hard | 1,500 |
| Red sand | 1,540 |
| Hard white sand | 1,960 |
| Red fine hard sand | 2,058 |

This boring was begun near the base of the Pierre shale, and the shales reported to a depth of 800 feet are mainly Niobrara and possibly the upper shale of the Benton. The "Dakota" sandstone appears to have been reached at 1,140 feet and to have continued to not far below 1,500 feet. The lower 300 feet or more were in the "Red Beds" and it was from them that the fresh water at 1,760 feet was obtained. The salt water at 890 feet was in sandstone of the Benton group. Apparently the "Dakota" sandstone yielded no water, a most discouraging indication, for its capabilities seem to have been thoroughly tested. The explanation probably is that, owing to the extensive outcrops of the "Dakota" formation, a short distance north and east, no head is possessed by whatever water may be passing through the sandstone. There is also a likelihood that the many dikes which penetrate the formations near Rouse Junction, particularly to the west, may cut off the underground flow.

*Walsenburg.*—At Walsenburg an unsuccessful boring was made sometime ago for gas. It was 1,300 feet deep and entirely in the Pierre shale, which here has a thickness of about 1,700 feet.

*Cuchara.*—On Cuchara River 7 miles below Walsenburg an 800-foot boring was made for coal, oil, or gas. It found an abundant supply of sulphur water, which is pumped to the surface. The boring probably reached the top of the "Dakota" sandstone.

*Elmoro.*—A 400-foot boring at Elmoro is entirely in Pierre shale and yielded no water.

*Salt Creek.*—This place is a siding on the Denver and Rio Grande Railroad at the crossing of Salado Creek, 6 miles south of Rouse Junction. The railroad company made a test boring to a depth of 2,030 feet, which did not find a sufficient supply of good water. Analyses of the two principal waters are given on pp. 80–81. The following materials were reported, but the record evidently is unreliable:

*Partial record of deep boring at Salt Creek siding, Las Animas County, Colo.*

| | Feet. |
|---|---|
| Gravel | 0– 6 |
| Hard limestone; water at 70 feet rose to —3 feet | 6– 71 |
| Black shale; thin limestone layers | 71– 250 |
| Sand and shales; water at 283 feet rose to —140 feet | 250– 285 |
| Black and white sand | 285– 335 |
| Gray sand | 335– 352 |
| Dark sand | 352– 365 |
| Light-gray sand | 365– 380 |
| Red sand and hard clay | 380– 410 |
| White shale; water at 440 feet rose to —220 feet | 410– 450 |
| Gray hard sandstone | 450– 495 |
| Greenish sand and sandstone | 495– 630 |
| Gray sand | 630– 750 |
| Dark-gray sand; water at 840 feet rose to —540 feet | 750– 845 |
| White sand | 845– 855 |
| Dark-gray sand | 855– 870 |
| Red sand; water at 1,005 feet rose to —705 feet | 870–1 015 |
| Red sand and "granite" | 1,025 |

At 1,545 feet water rose to —900 feet, and at 1,800 feet rose to —600 feet.

This boring began in the lower portion of the Pierre shale, penetrated the Niobrara from about 300 to about 950 feet, and the Benton from about 950 to about 1,350 feet, where the "Dakota" sandstone was entered. It is the latter formation which yields the water at 1,545 feet, a water too highly mineralized to be of any use. The lower 200 feet of the well were probably in "Red Beds." The failure of this well to yield a satisfactory water supply is in line with a similar experience at Rouse Junction, in the adjoining county to the north. The amount of water at Salt Creek was not ascertained, but it was believed not to be great. This and the experience of the Rouse Junction well indicate either that the water leaks out to the northwest, or that its circulation is impeded by the many dikes of igneous rock which intersect the formations in the surrounding region. This diminished circulation is also indicated by the salinity of the water, which we should expect would be greatly decreased if there were a free underground passage to the canyons north and east; moreover, in these canyons very little water is seen to come out of the formation.

*Boone.*—In 1903 a deep boring was made at Boone to explore for oil or gas. It reached the top of the "Dakota" sandstone, which was not penetrated sufficiently to afford a water supply. The following record is furnished:

*Record of boring at Boone, Colo.*

| | Feet. |
|---|---|
| Surface materials | 0– 25 |
| Shale | 25–1,560 |
| Limestone | 1,560–1,610 |
| Shale | 1,610–1.720 |
| Limestone | 1,720–1,740 |
| Shale with "talc vein" | 1,740–2,200 |
| "Dakota" sandstone | 2,200– |

The first 1,000 feet of shale probably are of the Pierre, while the Niobrara, with its Apishapa shales above and Timpas limestone below, extends to 1,740 feet, a thickness of about 740 feet. The Carlile, Greenhorn, and Graneros beds comprise a thickness of 460 feet. This boring is near the axis of a deep north-pitching syncline—a fact which accounts for the great thickness of Pierre shale.

*Pueblo.*—In 1903 two deep borings were sunk in north-central Pueblo County, with the hope of finding oil or gas, but without success. Both borings are situated north of Arkansas River—one 1,900 feet deep, 7 miles northeast of Pueblo, and the other 2,655 feet deep, 10 miles northeast of Pueblo. The shallower boring appears not to have reached the "Dakota" sandstone, but found some water which rose to within 550 feet of the surface. The 2,655-foot well penetrated the "Dakota" sandstone 55 feet and found water which rose 1,000 feet or more. The following records were furnished:

*Records of wells 7 and 10 miles northeast of Pueblo, Colo.*

| | Feet. |
|---|---|
| Well No. 1: | |
| Shale | 0–1,400 |
| Limestone | 1,400 |
| Sandstone | 1,440 |
| Shale | (?) 1,875 |
| Sandstone (probably Carlile) | 1,875–1,900 |
| Well No. 2: | |
| Shale | 0–2,000 |
| Limestone | 2,000–2,100 |
| Sandstone (Carlile) | 2,100–2,140 |
| Shale | 2,140–2,600 |
| "Dakota" sandstone | 2,600–2,655 |

The altitude of the first well is about 4,900 feet and its precise location is 4½ miles north and a half mile west of Baxter siding, on the Missouri Pacific Railroad. The other boring is at an altitude of 4,750 feet and its approximate location is 6 miles north and 3 miles west of Nyburg siding, on the Missouri Pacific Railroad. It is probable that if the "Dakota" sandstone had been more deeply penetrated by this boring the water would have risen to within 100 feet of the surface, but the boring is situated on land too high for artesian flow.

*Colorado City.*—Deep borings at Colorado City penetrated the steeply dipping beds of the foothills, but did not prove successful. Two deep wells were bored there by a local oil company in 1894 and 1895. Boring No. 1 was located on the NW. ¼ of NE. ¼ sec. 2, T. 14 S., R. 67 W. It reached a depth of 2,020 feet, where operations were stopped by the collapse of a string of casing. Below the first 30 feet of surficial materials the formation penetrated was black shale, except at 1,247 feet, where a 5-foot bed as hard as granite was reported, which yielded some gas. The boring was entirely in Pierre shale. Boring No. 2 was located on the SW. ¼ of NE. ¼ sec 2, T. 14 S., R. 67 W., and had a depth of 1,300 feet, entirely in shale below the first 60 feet. Both holes are now full of water.

*Calhan.*—A boring at Calhan, doubtless entirely in the Laramie formation, was sunk to a depth of 566 feet, and obtained a small amount of water at 90 feet. Coal-bearing beds were reported at 250 feet and lower, but the beds were thin and the coal was of poor quality. The following record was reported by the Chicago, Rock Island and Pacific Railroad Company:

*Record of boring at Calhan, Colo.*

| | Feet. |
|---|---|
| Sand | 0 - 23 |
| Sandstone | 23 - 38 |
| Dark sandy shale | 38 - 63 |
| Clay and sandy shale grading into soft sandstone | 63 -142 |
| "Soapstone;" thin coal layer at 232 feet | 142 -255 |
| Shale | 255 -306 |
| Sandy limestone | 306 -314 |
| Sandy shale with coaly layers | 314 -323 |
| "False coal" | 323 -324 |
| Fire clay | 324 -325½ |
| Dark shale | 325½-329 |
| Sandy shale | 329 -336½ |
| "False coal" | 336½-337 |
| Micaceous sandy shale; ½-inch coal layer at 360 feet | 337 -361 |
| "Soapstone" | 361 -416 |
| Micaceous sandy shale | 416 -432 |
| "False coal and poor coal" | 432 -435 |
| Shale | 435 -480½ |
| Sandy false coal | 480½-484½ |
| Poor coal | 484½-487 |
| Micaceous sandy layer with some shale | 487 -546 |
| Sandy false coal | 546 -551 |
| Shale | 551 -556½ |
| Shale and sandy shale | 556½-566 |

*Franceville Junction.*—At this place, which is on the slope southeast of Colorado Springs, a 1,250-foot boring is reported, which was entirely in Pierre shale and yielded neither water, oil, nor gas.

*Monument.*—A 765-foot boring is reported at Monument. It began in or above the Laramie beds and probably penetrated Pierre shale, but without result.

*Florence.*—In the oil fields about this place there are many deep borings, mostly in the Pierre shale, which rarely find much water. One with a depth of 3,021 feet was entirely in shale, except 10 feet of dark hard rock at 2,680 feet. It encountered no water.

### SOURCE OF THE "DAKOTA" WATER.

The artesian waters of the "Dakota" sandstone enter this formation in the outcrop zone along the foot of the Rocky Mountains and also in the wide area of exposures in the southeast corner of the State. The exposed surface of the sandstone directly absorbs a portion of the rainfall and some of the water of streams crossing the outcrop also sinks into the porous beds. In the southeast corner of the State the formation is extensively overlain by deposits of gravel and sand, and much of the water which falls on this surface passes underground and in part enters the "Dakota" sandstone. Some of the water absorbed on the higher ridges escapes again at lower levels along the canyons and draws, either in springs or as small seeps. These are occasionally observed along the hillsides, and doubtless there are many others covered by talus and wash.

The area of "Dakota" sandstone exposed in the "hogbacks" along the foot of the mountains is relatively small; the outcropping beds usually dip steeply, and much of the rock is so hard that water falling upon its surface runs off into the adjoining shale valleys, so that probably only a limited amount passes underground in this zone. Probably most of the water is absorbed in the wide outcrop area extending from Huerfano River to Apishapa River, northwest of Thatcher, and especially in the wide plateaus south and southeast of La Junta. In the latter area the sandstone constitutes the surface for many square miles; much of the land is level or gently sloping and the sandstone is soft, so that it is capable of absorbing a large volume of water. On the other hand, this region is traversed by numerous deep canyons cut entirely through the "Dakota" sandstone, so that part of the underground drainage of the formation is intercepted. Purgatory River and Smith and Muddy creeks probably intercept all of the underground drainage of the sandstone in the region north and northwest of the Mesa de Maya.

### DEPTHS TO "DAKOTA" SANDSTONE.

Owing to the irregular dips of the rocks in southeastern Colorado, the depth to the water-bearing "Dakota" sandstone varies considerably in different portions of the district. From a study of the distribution of the overlying formations and a knowledge of their thickness, obtained by measurements on the surface and in wells, the position of the top of the "Dakota" sandstone has been ascertained as shown on the map, Pl. XXV. This map also shows the area in which the "Dakota" sandstone is at or near the surface and the region in which there is no "Dakota" sandstone. It will be seen from this illustration that, along the greater part of the Arkansas Valley, the water-bearing horizon lies at a moderate distance below the surface and over wide areas it is within the reach of wells 300 to 1,500 feet deep. In a wide district extending from northeast of Pueblo to northwest of Ordway the strata dip steeply into a deep basin, so that in northeastern Pueblo County, northwestern Otero County, central and eastern El Paso County, and Lincoln County the "Dakota" sandstone lies too deep for well drilling, and, moreover, the land in this region is too high for the water to flow. The beds also lie in a deep basin in central and southern Huerfano and Las Animas counties, as well as in the area about Florence. From Portland to Pueblo, in the vicinity of Arkansas River, the "Dakota" sandstone is less than 1,200 feet below the surface, and in a small anticline 6 miles west of Pueblo the top of the formation is exposed in the river bed. East of this exposure the dips increase gradually, so that the depths are about 1,200 feet at Pueblo, 1,900 feet at Nyburg, and about 2,000 feet at Boone, which is near the center of the basin. East of Boone the amounts diminish gradually, being 1,800 feet at Nepesta, 1,270 feet at Fowler, 1,033 feet at Manzanola, 690 feet at Rocky Ford, and 340 feet at La Junta. There is still further decrease to Las Animas, a short distance east of which the "Dakota" sandstone reaches the surface, outcropping along the bottom of the valley nearly to the mouth of Big Sandy Creek. East of this point the dip carries the beds down again and the depths gradually increase to 405 feet at Granada, which is in the center of a shallow basin. On the east slope of this basin there is a gradual rise to a depth of 200 feet at Coolidge. Many of these features are shown on Pls. XXIII, XXV, and XXVI.

The figures above given are to the surface of the "Dakota" sandstone, and, while in many districts a flow of water is obtainable from the top bed of this formation, the principal supply is usually looked for in lower beds, 100 to 160 feet deeper. In Kiowa County a prominent anticline extends northward from the Arkansas Valley, raising the beds in a low arch which extends northward to Kit Carson County. Owing to this uplift the "Dakota" sandstone lies at moderate depths as far north as the Union Pacific Railroad, especially in the lowlands of Big Sandy and Big Spring creeks. Unfortunately, however, all of this region is too high for artesian flows. Along the Rocky Mountain front the "Dakota" sandstone varies greatly in attitude, and in the vicinity of Colorado Springs and for several miles north and south the dips are steep and the sandstones are carried rapidly beneath the surface, soon reaching a depth of 3,000 feet. In the region northwest of Pueblo where the dips are gentler, the depths are much more moderate and the sandstone may be reached by wells 200 to 1,000 feet deep over an area of considerable extent. Along the base of the Wet Mountain Range the "Dakota" sandstone is extensively exposed, except to the south near Huerfano River, where it dips steeply under the great basin in which the Spanish Peaks are situated. On the east side of this basin there is a zone passing through Huerfano, Cuchara, Hoehne, Elmoro, Barela, Trinchera, and Watervale, in which there is a gradual increase of depth from east to west of 600 to 1,500 feet in greater part.

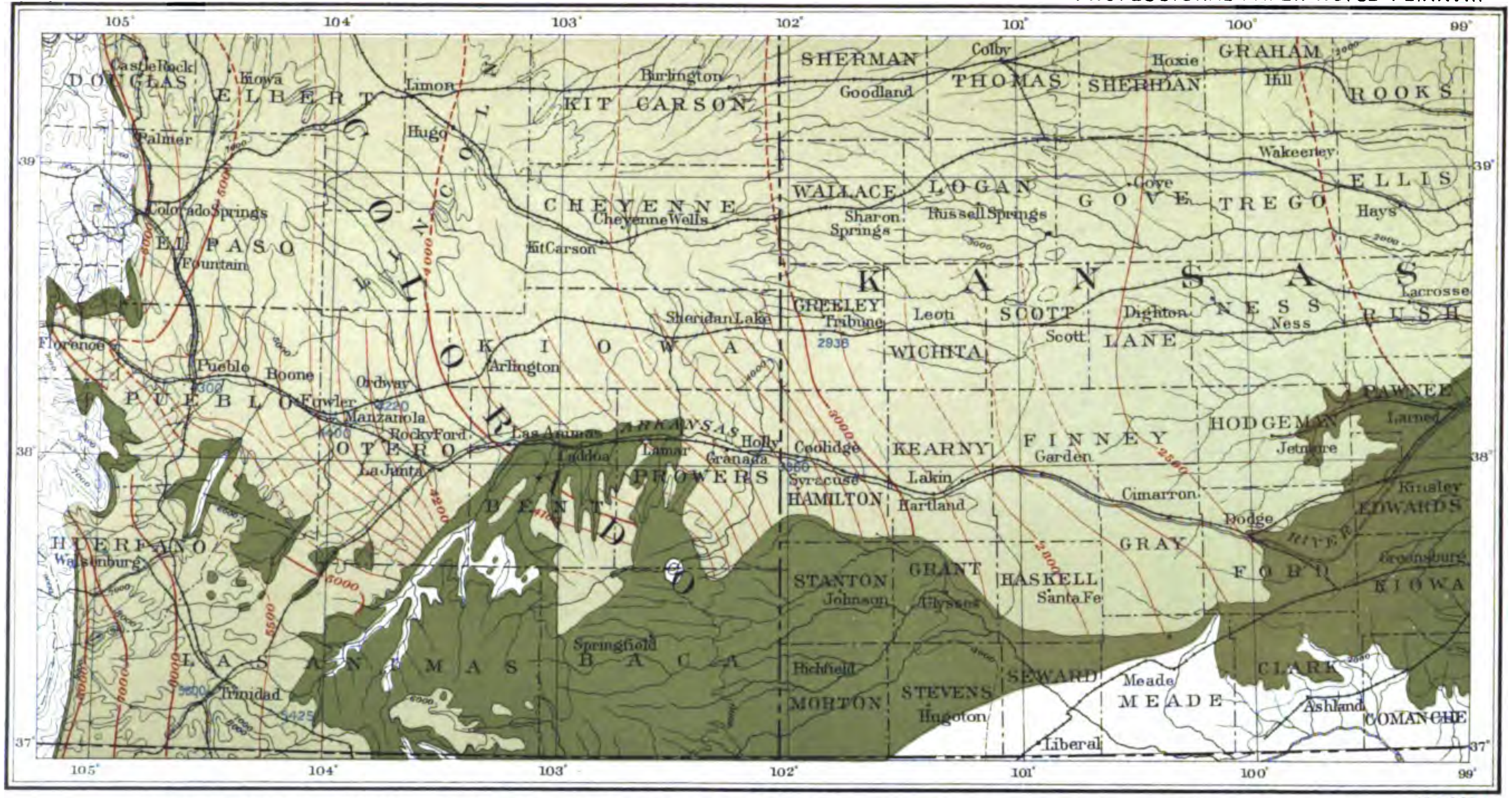
## AREA OF FLOW.

Apparently the "Dakota" sandstone contains water throughout its extent, especially where it passes underground below the younger formations. As explained above, the sandstone receives much of the water at moderately high elevation, so that this water possesses considerable head in its passage underground. This head is sufficient to afford flows in nearly all of the lower lands near Arkansas River and along some of the confluent valleys, especially to the west. The areas in which flows may be expected are shown by the overprinted pattern on the map, Pl. XXV. This representation is based on the observed pressures in wells, together with deductions as to gradient slopes drawn between many points along the outcrops of the water-bearing beds. These lines of the grade of the water head have been found to slope from the outcrops at high levels, where the water passes underground, to the outcrops at lower levels where there is leakage from springs. The principal area of low-level leakage in the district is along Arkansas River, between Las Animas and the mouth of Big Sandy Creek, where the "Dakota" sandstone is free to lose much of its water, consequently the head of the water becomes zero along this outcrop zone. The hydrostatic gradient rises to the southwest, but not rapidly, owing to the low declivity of the Purgatory Valley, which cuts into and through the sandstone for many miles. West of longitude 104° the rate of increase is very much higher, although it is locally diminished by the deep valleys of Apishapa and Huerfano rivers. Although the sandstones lie high on the mountain slopes in the western portion of Pueblo and the eastern portion of Fremont counties, there is a rapid diminution of head toward Pueblo, possibly due in part to the rise of the formation to the surface along the river 6 miles west of Pueblo.

The flowing wells south of Portland, at Pueblo, Fowler, Manzanola, Rocky Ford, Holbrook, La Junta, and Amity are along the main zone of flow. At La Junta there was originally a flow of considerable pressure, and also at Lamar, but pumping has reduced the water level considerably below the present surface of the land. Flows at Timpas and Thatcher show an extension of the flow area to the southwest up the Timpas Valley, and similar lateral extension may be expected in the Apishapa, Huerfano, St. Charles, and other large valleys leading into Arkansas River. At Ordway and Sugar City the water-bearing beds appear to have been reached, but the land was too high for a flow and this probably was also the case at Sheridan Lake and Kit Carson in the wells sunk and abandoned long ago. The Government well northeast of Fort Lyon evidently was near the northern margin of the flow area, as its pressure was very slight, and two wells to the north and northwest have water levels considerably below the surface. The well 10 miles due south of Portland indicates a wide extension of the flow area in the southeast corner of Fremont County and adjacent portions of Pueblo County. A small flowing well on Plum Creek 20 miles south of Granada indicates that flows may be expected in the lower valleys in the central-eastern portion of Prowers County, probably as far south as South Butte Creek. The water level 100 feet below the surface at Trinidad and 80 feet below the surface at Barela indicates that the area of flow does not extend as far up Purgatory River and its branch valley as originally supposed.

### PRESSURE OR HEAD OF THE WATERS.

As explained above, the waters in the "Dakota" sandstone under the greater part of southeastern Colorado possess considerable pressure, which ordinarily is sufficient to bring the water to the surface and in portions of the district to carry it to a greater or less distance above. In Pueblo the wells have a pressure of 50 pounds to the square inch, and at Manzanola it is reported that the original pressure was 55 pounds. At Rocky Ford and Holbrook the water was found to have sufficient pressure to rise 80 feet, or more, in the pipe. At La Junta the well south of the town is about 150 feet higher than the depot, and when the well was first sunk the water had sufficient force to rise considerably above the surface. A heavy draft on the water supply at La Junta has since lowered the water level so greatly that even the wells on the lower land do not flow. In Pl. XXVIII the head of the waters is shown, and in the following table are given data from various flowing and nonflowing wells, throwing light on the head of waters in the "Dakota" sandstone. Unfortunately, it was impracticable to obtain the pressures, or facts relating to the water level, in some of the wells, and even the figures given in most cases are only approximate.



A. Hoen & Co. Baltimore.

## MAP OF PART OF THE ARKANSAS VALLEY, SHOWING HEAD OF WATER IN "DAKOTA" SANDSTONE

BY N. H. DARTON

1905

Figures in blue indicate altitude of head at wells

——7000—— Artesian head (contour lines showing approximate altitude to which the artesian waters may rise. Intervals vary from 100 to 500 feet)

Scale

20 10 0 20 40 60 miles

Black contours have 1000-foot intervals; broken lines hypothetical

☐ Area underlain by "Dakota" sandstone

■ Outcrop area of "Dakota" sandstone

*List of wells in eastern Colorado affording data as to head of waters.*

| Locality. | Height to which water will rise. | Altitude of the land. | Head of water above sea level. |
|---|---|---|---|
| FLOWING WELLS. | *Feet.* | *Feet.* | *Feet.* |
| Portland (10 miles south) | 100± | 5,550 | 5,650± |
| Florence (6 miles north) | + 80 | 5,400 | +5,480 |
| Pueblo (South) | 138 | 4,750 | 4,888 |
| Farriss House | 138 | 4,670 | 4,810 |
| Grand Hotel | 115 | 4,690 | 4,805 |
| Rocky Ford | 80 | 4,177 | +4,257 |
| Manzanola | ?126½ | 4,251 | ?4,377 |
| La Junta (originally) | +150 | 4,061 | +4,210 |
| Holbrook | + 80 | 4,260 | 4,340 |
| Timpas | + 27 | 4,480 | +4,507 |
| Bloom | + 50 | 4,691 | +4,741 |
| Fort Lyon | 10 | 3,955 | 3,965 |
| Blackwell ranch (Plum Creek) | 46 | 3,900 | 3,946 |
| NONFLOWING WELLS (WATER BELOW SURFACE). | | | |
| Ordway | − 80 | 4,300 | 4,220 |
| Arlington (10 miles southwest) | − 60 | 4,180 | 4,120 |
| Las Animas (10 miles north) | −300 | 4,100 | 3,800 |
| Caddoa | − 15± | 3,765 | 3,750± |
| Lamar | 0 | 3,592 | 3,592 |
| Granada | − 25 | 3,445 | 3,420 |
| Amity | − 19 | 3,450 | 3,431 |
| Amity (3 miles north) | −100 | 3,550 | 3,450 |
| Delhi | − 50 | 5,057 | 5,007 |
| Trinidad | −195 | 5,980 | 5,785 |
| Barela | −300 | 5,723 | 5,423 |
| Wetmore (1½ miles east) | −100 | 6,000 | 5,900 |
| Sheridan Lake | − 50 | 4,065 | 4,015 |
| Rouse Junction | −200 | 6,128 | 5,928 |
| Salt Creek | −900 | 6,480 | 5,580 |

The lines in Pl. XXVIII are constructed from the altitudes of "Dakota" sandstone outcrops and the water levels given in the above table. It is assumed that the gradients of head are uniform from point to point, as shown in the diagram, fig. 2, and this is found to be verified at numerous points in the Arkansas Valley.

## QUANTITY OF "DAKOTA" WATERS.

The volume of water available from the "Dakota" sandstone in eastern Colorado is variable, and in portions of the region it has been found inadequate. The three principal factors in this connection are the original volume of supply, the head of the water, and the porosity of the sandstone. No matter how much water is available along the intake zone, nor the head that may be developed in its passage to lower levels, there can be but little volume of water available if the sandstone is not porous. In its surface outcrops, as well as in the borings, the rock is found to vary considerably in porosity, but in general it usually appears to be capable of holding a moderately large volume of water. The amount of water that passes underground seems to be large, judging from the wide area of the formation exposed and its surface porosity, but much of the water taken in at high altitudes is free to escape at lower ones, so that from this cause there is not only loss of water but diminution of head. Where the rock is saturated with water and the head is high, a well tapping the sandstone will yield a larger flow than one in an area where the pressure is low. As heretofore explained, nearly all the pressures in the Arkansas Valley are low, so that there is relatively little power to force the water into the sandstone interstices in the vicinity of the well, so as to sustain a vigorous flow. In most of the wells in the Arkansas Valley only a moderate volume of water was found, and, when the wells are subjected to pumping, the water surface is quickly lowered in most cases.

The wells at Rocky Ford exhibit a larger volume of water than any others in the Arkansas Valley below Pueblo. Of the several that have been bored, the larger ones have sustained a flow of 100 to 115 gallons a minute. The well at Manzanola, only 10 miles west, yields less than 40 gallons a minute, and the well at Fowler only half a gallon a minute. This rapid diminution to the west apparently is due to diminished porosity of the sandstone. There is similar but less marked diminution to the east, as illustrated at La Junta. At this place there are several wells which originally flowed 12 to 35 gallons a minute, but vigorous pumping has lowered the head greatly and materially diminished the volume. North and northwest of La Junta the volume increases, a flow of 100 gallons a minute being reported at Holbrook. About Las Animas the wells have flows of 10 to 20 gallons. At Caddoa, Lamar, Granada, and Amity, where the waters are pumped, supplies of 40 to 80 gallons a minute are obtained. In the various wells along the Santa Fe Railroad southwest of La Junta the amount of water flowing or available for pumping varies greatly. At Delhi 37 gallons and at Tyrone 50 gallons are obtained. At Timpas and Thatcher the volume was very small, but at Ayer the poor water obtained had a flow of 25 gallons. In the vicinity of Pueblo the volume also is variable. The first well in South Pueblo flows 100 gallons a minute, of mineral water, while other wells in the vicinity flow 13 to 25 gallons.

The well having the largest flow in the Arkansas Valley is the one 10 miles south of Portland, where, from a depth of about 1,100 feet, about 600 gallons a minute flow from a 6-inch casing. It is possible that the large amount of water in this locality is due to the proximity to the intake zone along the mountain front a short distance south and west. It gives promise that in the extensive prairies lying east and north, similar large flows may be obtained, which could be used extensively for irrigation.

In the eastern portion of Huerfano and the western portion of Las Animas counties there appears to be but a limited supply of water in the "Dakota" sandstone, except about Trinidad and southeastward, where some of the wells obtain fair supplies by pumping. Deep borings at Rouse Junction and Salt Creek, on the Denver and Rio Grande Railroad, found only a very small amount of water in the "Dakota" sandstone, and at the latter place it was too much mineralized for use. Probably the small volume of water in this district is due to the escape of the underground supplies in the outcrops of "Dakota" sandstone at lower levels to the east. Possibly also the flow of underground currents is greatly impeded by the numerous igneous masses which traverse the strata in many directions.

### QUALITY OF THE "DAKOTA" WATERS.

All waters which flow over or through rocks and soil dissolve various chemical compounds, the nature and amount of which have great local variation. Water passing through pure sand or sandstone can be contaminated only to a very slight degree, but nearly all rocks contain soluble minerals, especially shales, limestones, and red beds, which often yield a large amount of salts to waters which come in contact with them. Red beds generally contain gypsum and salts of various kinds and yield highly mineralized waters. The deep waters of the Arkansas Valley vary greatly in quality, but nearly all contain a noticeable amount of mineral matter. Only a few analyses are available, and these are given in the following tables. The chemicals are reported in their theoretic combinations, and it should be pointed out in this connection that there is considerable difference of opinion among chemists as to the probable compounds indicated by analyses. Most of the waters from the "Dakota" sandstone in the Arkansas Valley region contain 50 to 100 grains per gallon of minerals. Sulphate of soda, or Glauber's salts, is the most prominent constituent, usually with smaller amounts of sodium chloride, or common salt, and sodium carbonate. Small amounts of carbonates of lime and magnesia appear in all the analyses reported, and usually there is also some sulphate of lime or gypsum.

In some districts the quality is satisfactory; in others the waters are much mineralized. In the vicinity of Pueblo the principal flow contains so large an amount of saline ingredients that it is regarded as a valuable medicinal agent and is extensively bottled as such. At Grand Hotel the flow at 1,050 feet near the top of the "Dakota" sandstone is reported to be of excellent quality. At Fowler, Manzanola, Rocky Ford, La Junta, Las Animas, Caddoa, Lamar, and Granada the quality is very satisfactory. At Ayer and Thatcher the water contains too much mineral for use in locomotives, while at Trinidad and Barela it is satisfactory for this use. In the well 10 miles south of Portland the water contains considerable iron, but appears to be satisfactory for drinking and irrigation. At Salt Creek and Rouse Junction waters of decidedly saline character were reported. At St. Mary the water is too alkaline for use.

*Analyses of waters from "Dakota" sandstone in southeastern Colorado.*

[Parts per million.]

| Locality. | Depth. | Sodium. | Potassium. | Calcium. | Magnesium. | Sulphuric acid. | Chlorine. | Carbonic acid. | Silica. | Iron oxide+aluminum oxide. | Organic and volatile. | Other constituents. | Total solids. | Year. | Analyst. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | *Feet.* | *Na.* | *K.* | *Ca.* | *Mg.* | *SO₄.* | *Cl.* | *CO₃.* | *SiO₂.* | *Fe₂O₃+Al₂O₃.* |  |  |  |  |  |
| Granada | 580 | 160 | ........ | 48 | 6.0 | 133 | 28 | 186 | ........ | ........ | 40 | ........ | 602 | 1899 | W. A. Powers. |
| Lamar | 226 | 368 | ........ | 42 | 27 | 692 | 33 | 114 | 49 | ........ | ........ | ........ | 1,325 | ........ | Do. |
| Do | 500 | 543 | ........ | 96 | 39 | 853 | 54 | 369 | 17 | ........ | 72 | ........ | 2,043 | 1897 | Do. |
| Do | 300 | 355 | ........ | 42 | 27 | 717 | 33 | 114 | 50 | ........ | ........ | ........ | 1,338 | ........ | Dearborn Drug Co. |
| Caddoa | 50 | 32 | ........ | 46 | 10 | 89 | 19 | 63 | ........ | ........ | 59 | ........ | 318 | ........ | W. A. Powers. |
| Do | 280 | 436 | ........ | 142 | 114 | 922 | 31 | 462 | ........ | ........ | 267 | ........ | 2,375 | 1899 | Do. |
| Las Animas | 340 | 380 | ........ | 14 | 7.2 | 440 | 18 | 244 | ........ | ........ | 40 | ........ | 1,144 | 1899 | Do. |
| La Junta | 439 | 360 | 6.4 | 74 | 20 | 676 | 54 | 170 | 16 | 1.71 | ........ | 0.17 | 1,378 | 1895 | W. F. Hillebrand. |
| Do | 420 | 415 | ........ | 16 | 7.4 | 578 | 58 | 171 | 20 | ........ | 96 | ........ | 1,362 | 1898 | W. A. Powers. |
| Do | 420 | 358 | ........ | 5.5 | 4.4 | 520 | 24 | 140 | 17 | ........ | 39 | ........ | 1,108 | 1898 | Do. |
| Do | 425 | 524 | ........ | 14 | 18 | 695 | 33 | 286 | 12 | 7.3 | 37 | 6.0 | 1,627 | ........ |  |
| Rocky Ford | 700? | 259 | 7.0 | 15 | 12 | 454 | 28 | 96 | 12 | 4.0 | ([a]) | 2.2 | 888 | 1895 | W. F. Hillebrand. |
| Timpas | 554 | 630 | ........ | 84 | 39 | 1,180 | 70 | 247 | 15 | 125 | ........ | ........ | 2,390 | ........ | W. A. Powers. |
| Do | 580 | 255 | ........ | 90 | 54 | 775 | 31 | 91 | 16 | ........ | 104 | ........ | 1,416 | ........ | Do. |
| Do | 620 | 260 | ........ | 118 | 72 | 905 | 21 | 108 | ........ | ........ | 140 | ........ | 1,624 | 1898 | Do. |
| Do | 755 | 312 | ........ | 264 | 42 | 1,190 | 24 | 141 | ........ | ........ | 215 | ........ | 2,189 | 1899 | Do. |
| Ayer | 252 | 638 | ........ | 31 | ........ | 756 | 133 | 295 | ........ | ........ | 48 | ........ | 1,901 | ........ | Do. |
| Do | 267 | 702 | ........ | 35 | ........ | 933 | 104 | 295 | ........ | ........ | 70 | ........ | 2,140 | ........ | Do. |
| Do | 311 | 182 | ........ | 98 | 30 | 575 | 25 | 76 | ........ | ........ | 113 | ........ | 1,098 | ........ | Do. |
| Do | 340 | 135 | ........ | 97 | 41 | 487 | 21 | 101 | ........ | ........ | 80 | ........ | 963 | ........ | Do. |
| Bloom | 240 | 89 | ........ | 91 | 46 | 411 | 16 | 96 | ........ | ........ | 96 | ........ | 845 | 1899 | Do. |
| Do | 358 | 109 | ........ | 76 | 40 | 418 | 18 | 80 | 13 | ........ | 119 | ........ | 873 | 1899 | Do. |
| Delhi | 322 | 107 | ........ | 166 | 50 | 666 | 14 | 85 | ........ | ........ | 112 | ........ | 1,200 | ........ | Do. |
| Tyrone | 580 | 213 | ........ | 140 | 31 | 317 | 125 | 260 | ........ | ........ | 62 | ........ | 1,148 | ........ | Do. |
| Pueblo (Farriss) | 1,400 | 249 | ........ | 60 | 30 | 526 | 25 | 139 | 16 | 16 | ........ | ........ | 1,061 | ........ | Von Schultz & Low, Pueblo. |
| (C. C. & I. Co.) | 1,260 | 242 | 16 | 103 | 57 | 683 | 34 | 169 | 9.4 | 20 | ........ | ........ | 1,334 | ........ | H. L. Wells. |
| (Grand Hotel) | 1,219 | 202 | 79 | 177 | 232 | 1,175 | 186 | 270 | ........ | 71 | ........ | 108 | 2,499 | ........ | A. A. Cunningham. |
| Salt Creek siding | 1,545 | 2,515 | ........ | 542 | 159 | 3,235 | 2,615 | 258 | 6 | ........ | ........ | 20 | 9,350 | ........ | Denver and Rio Grande R. R. Co. |

[a] Present.

These constituents may be hypothetically combined as follows:

*Analyses of waters from "Dakota" sandstone in southeastern Colorado.*

[Expressed in hypothetical combinations and in grains per gallon.]

| Locality | Depth. | Sodium sulphate. | Sodium chloride. | Sodium carbonate. | Potassium chloride. | Calcium sulphate. | Calcium carbonate. | Magnesium carbonate. | Magnesium sulphate. | Silica. | Iron and alumina. | Organic and volatile matters. | Other constituents. | Total. | Year. | Analyst. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Feet.* | | | | | | | | | | | | | | | |
| Granada (railroad) | 580 | 11.50 | 2.72 | 10.48 | | | 7.08 | 1.22 | | | | 2.33 | | 35.33 | 1899 | W. A. Powers. |
| Lamar (railroad) | 226 | 59.87 | 3.20 | .19 | | 2.11 | 4.52 | 5.43 | | 2.89 | | | | 78.21 | | Do. |
| Do | 500 | 73.84 | 5.17 | 13.33 | | | 13.98 | 7.95 | | 1.02 | | 4.20 | | 119.49 | 1897 | Do. |
| Lamar (city well) | 300 | 60.08 | 3.21 | | | | 6.07 | 4.26 | 1.69 | 2.92 | | | | 78.23 | | Dearborn Drug Co. |
| Caddoa (railroad) | 50 | 3.45 | 1.88 | | | 4.04 | 3.69 | 2.09 | | | | 3.45 | | 18.60 | 1899 | W. A. Powers. |
| Do | 280 | 75.21 | 3.04 | | | 4.39 | 17.53 | 23.17 | | | | 15.63 | | 138.97 | 1899 | Do. |
| Las Animas (railroad) | 340 | 38.09 | 1.78 | 21.15 | | | 2.08 | 1.47 | | | | 2.33 | | 66.90 | 1899 | Do. |
| La Junta (railroad) | 439 | 58.33 | 4.66 | .64 | 0.70 | | 10.73 | 4.20 | | .93 | 0.10 | | 0.01 | 80.30 | 1895 | W. F. Hillebrand. |
| Railroad well | 420 | 50.03 | 5.60 | 13.40 | | | 2.30 | 1.50 | | 1.20 | | 5.60 | | 79.63 | 1898 | W. A. Powers. |
| Railroad well No. 2 | 420 | 45.00 | 2.30 | 12.50 | | | .80 | .90 | | 1.00 | | 2.30 | | 64.80 | 1898 | Do. |
| Flouring mill | 425 | 60.16 | 3.18 | 22.84 | | | 2.12 | 3.57 | | .72 | .43 | 2.16 | | 95.18 | | Do. |
| Rocky Ford | 700? | 39.14 | 1.87 | 3.90 | .76 | | 2.16 | 2.51 | | .70 | .35 | | .35 | [a] 51.74 | 1895 | W. F. Hillebrand. |
| Timpas | 554 | 102.08 | 6.73 | 2.53 | | | 12.24 | 7.96 | | .99 | | 7.29 | | 139.82 | | W. A. Powers. |
| Do | 580 | 42.44 | 2.98 | | | 17.85 | | 7.48 | 5.06 | .93 | | 6.10 | | 82.84 | | Do. |
| Do | 620 | 44.20 | 2.30 | | | 23.52 | | 8.89 | 8.11 | | | 8.16 | | 95.18 | 1898 | Do. |
| Do | 755 | 53.41 | 2.31 | | | 33.72 | 13.79 | | 12.13 | | | 12.59 | | 127.95 | 1899 | Do. |
| Ayer | 252 | 65.40 | 12.80 | 25.60 | | | 4.60 | | | | | 2.80 | | 111.20 | | Do. |
| Do | 267 | 80.80 | 10.00 | 25.20 | | | 5.10 | | | | | 4.10 | | 125.20 | | Do. |
| Do | 311 | 29.90 | 2.40 | | | 19.00 | .30 | 6.00 | | | | 6.60 | | 64.20 | | Do. |
| Do | 340 | 22.00 | 2.00 | | | 19.30 | | 8.30 | | | | 4.70 | | 56.30 | | Do. |
| Bloom | 240 | 14.03 | 1.63 | | | 18.13 | | 7.87 | 2.22 | | | 5.60 | | 49.48 | 1899 | Do. |
| Do | 358 | 17.67 | 1.69 | | | 15.15 | | 6.59 | 2.27 | .75 | | 6.99 | | 51.11 | 1899 | Do. |
| Delhi | 322 | 17.72 | 1.35 | | | 32.92 | | 6.97 | 4.69 | | | 6.53 | | 70.18 | | Do. |
| Tyrone | 580 | 23.68 | 12.07 | | | 3.59 | 17.84 | 6.37 | | | | 3.65 | | 67.20 | | Do. |
| Florence (6 miles north) | 1,230 | | 13.61 | 15.95 | | 26.71 | 11.37 | 18.97 | | | | 20.30 | | 106.90 | 1905 | Wm. P. Hadden. |
| Pueblo (Fariss) | 1,400 | 41.92 | 2.42 | | | 3.43 | 6.28 | 6.16 | | .91 | .91 | | | 62.03 | | Von Schultz & Low, Pueblo. |
| (C. C. & I. Co) | 1,260 | 41.43 | 1.82 | | 1.82 | 16.94 | 2.64 | 11.65 | | .55 | 1.17 | | | 78.02 | | H. L. Wells. |
| (Grand Hotel) | 1,219 | 22.92 | 11.02 | | 8.81 | | 25.90 | .35 | 66.67 | | 4.14 | | 6.30 | [b] 146.11 | | A. A. Cunningham. |
| Salt Creek siding | 1,545 | 113.30 | 252.40 | 25.16 | | 107.60 | | | 45.99 | .35 | | | 1.20 | 546.00 | | Denver and Rio Grande R. R. Co. |

[a] Including lithium chloride, 0.17; ammonium carbonate, 0.12; strontium carbonate, 0.06; and manganese carbonate, trace.

[b] Including lithium chloride, 6.3.

In the analysis of the water of the first well at La Junta it is reported that when the analysis was made the water had deposited a slight brown sediment containing iron, manganese, silica, and a trace of phosphoric acid, all of which, except the last, are included in the analysis. Free and semicombined carbonic acid ($CO_2$), 124.4 parts per milion; total $CO_2$, 250.2 parts per million. A trace of lithium was found.

When the water from the first artesian well at Rocky Ford was received in Washington it had deposited a sediment containing silica, iron oxide, a trace (?) of alumina, and phosphoric oxide. Traces of bromides (?), iodides, and phosphates were found in the water and some organic matter not determined. Boron, fluorine, and barium were absent. Free and semicombined carbonic acid ($CO_2$), 106.57 parts per million; total $CO_2$, 176.90 parts per million.

### WATERS OF THE "RED BEDS" AND THE MORRISON FORMATION.

Under the greater part of southeastern Colorado the top of the "Red Beds" lies 100 to 300 feet below the base of the "Dakota" sandstone. In the region north of Arkansas River and east of Fountain Creek these "Red Beds" are too deep to be reached by ordinary well drilling, but along the river valley and southward they are at moderate depths. The deep borings at La Junta, Manzanola, Thatcher, Rouse Junction, Salt Creek, Caddoa, Fort Lyon, and Bloom penetrated more or less deeply into the "Red Beds," but obtained no satisfactory water supplies. At a few points in Kansas the "Red Beds" have been found to contain good water, but in most cases it is too highly mineralized to be of any use. Probably water-bearing strata will be found in the "Red Beds" in Colorado, but it is doubtful if any of them will yield useful supplies, and ordinarily a boring should be discontinued as soon as it enters the "Red Beds." The Morrison formation includes thin beds of sandstone which often contain water, but the amount so far found is too small to be of value. At Manzanola the "Red Beds" were penetrated from 1,653 to 2,110 feet and several water-bearing strata were found, but it is reported that the water was very impure. In the Bloom boring, the "Red Beds" extend from 455 to 1,162 feet and yielded some water of bad quality at 1,006 and 1,145 feet, of which analyses are given in the table below. At Rouse Junction the water found in the "Red Beds" at a depth of 1,760 feet was reported as "fresh," but it rose only about 200 feet. The following are analyses, made by W. A. Powers, for the Atchison, Topeka and Santa Fe Railway Company, of waters from the "Red Beds" at Bloom and from the Morrison formation at La Junta and Caddoa, at the depths stated:

*Analyses of waters from "Red Beds" and Morrison formation in eastern Colorado.*

[Parts per million.]

| Constituent. | Bloom. | | La Junta. | | Caddoa. | |
|---|---|---|---|---|---|---|
| | 1,006 feet. | 1,145 feet. | 663 feet. | 757 feet. | 440 feet. | 560 feet. |
| Sodium, Na | 2,131 | 846 | 323 | 270 | 586 | 753 |
| Potassium, K | | | | | | |
| Calcium, Ca | 146 | 229 | 23 | 12 | 143 | 38 |
| Magnesium, Mg | 88 | 65 | 24 | 6.4 | 75 | 28 |
| Sulphuric acid, $SO_4$ | 1,844 | 1,342 | 572 | 424 | 1,282 | 702 |
| Chlorine, Cl | 221 | 254 | 24 | 11 | 39 | 82 |
| Carbonic acid, $CO_3$ | 1,871 | 553 | 136 | 109 | 329 | 587 |
| Silica, $SiO_2$ | | | 56 | 17 | | |
| Iron oxide+aluminum oxide, $Fe_2O_3+Al_2O_3$ | | | | | | |
| Organic and volatile | 255 | 138 | 66 | 58 | 199 | 136 |
| Other constituents | | | | | | |
| Total solids | 6,556 | 3,427 | 1,224 | 907.4 | 2,653 | 2,321 |

*Analyses of waters from "Red Beds" and Morrison formation in eastern Colorado.*

[Expressed in hypothetical combinations and in grains per gallon.]

| Constituent. | Bloom. | | La Junta. | | Caddoa. | |
|---|---|---|---|---|---|---|
| | 1,066 feet. | 1,145 feet. | 663 feet. | 757 feet. | 440 feet. | 560 feet. |
| Sodium sulphate | 159.63 | 116.13 | 49.54 | 36.70 | 101.18 | 60.79 |
| Sodium chloride | 21.29 | 24.56 | 2.31 | 1.40 | 3.73 | 7.96 |
| Sodium carbonate | 148.36 | 4.92 | 4.40 | 7.70 | | 48.72 |
| Calcium sulphate | | | | | 9.38 | |
| Calcium carbonate | 21.30 | 33.61 | 3.32 | 1.80 | 13.94 | 5.62 |
| Magnesium sulphate | | | | | | |
| Magnesium carbonate | 17.85 | 13.20 | 4.90 | 1.30 | 15.31 | 4.77 |
| Silica | | | 3.26 | 1.00 | | |
| Iron and alumina | | | | | | |
| Organic and volatile matters | 14.93 | 8.08 | 3.85 | 3.40 | 11.66 | 7.93 |
| Total solids | 383.36 | 200.50 | 71.58 | 53.30 | 155.20 | 135.79 |

## WATERS OF LARAMIE AND ASSOCIATED FORMATIONS.

The Fox Hills (Trinidad), Laramie, and overlying formations all contain water, but unfortunately these formations are so distributed that their water supplies are not likely to be very useful. The area extending from the Raton Mesa to the Spanish Peaks and beyond is a rough upland of high ridges and steep-sided valleys, and, moreover, the conditions are not favorable for flowing wells, except possibly in some of the deeper valleys. In the large synclinal area east of Colorado Springs well water is obtainable at various depths in the Laramie and associated beds, a few ranches drawing their supplies from this source. A deep well at Calhan, described on page 72, failed to obtain satisfactory water supplies in the Laramie formation, and there was a similar experience with a well at Monument.

In the Florence basin the Laramie formation lies at moderate depths and doubtless will prove to be water bearing. Some of the wells west of Florence obtained a moderate amount of water from this source, and in some of the coal mines there is sufficient water to be an obstacle to mining operations.

### WATERS OF THE LATER TERTIARY DEPOSITS.

In the wide areas covered by later Tertiary deposits abundant water supplies are usually obtainable for pump wells. The deposits consist of various materials which absorb a large proportion of the rainfall. This water sinks low in the deposits, and usually the largest amounts are found in the basal portions lying on the Pierre and Niobrara shales. Where the contact of the shales and overlying sands is exposed there are usually springs, by which a portion of the water escapes to the surface.

Wells in the later Tertiary deposits vary in depth from 10 to 250 feet, the deepest ones being in the eastern portion of Cheyenne County. At Cheyenne Wells a large supply of excellent water is obtained at the base of the later Tertiary deposits at a depth of 257 feet. Ordinarily a large supply is found in these lower gravels, but it is well known among drillers that after the shale is reached it is useless to sink deeper.

### WATERS IN THE DUNE SANDS.

Owing to their porous nature the dune sands absorb a large percentage of the water that falls upon them, and they usually lie in such manner as to intercept more or less of the surface run-off from the adjoining slopes. Accordingly they accumulate considerable water and afford excellent supplies for shallow wells throughout their area.

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UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

# GEOLOGY AND WATER RESOURCES
OF THE
# BIGHORN BASIN, WYOMING

BY

CASSIUS A. FISHER

ACBuston.

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# GEOLOGY AND WATER RESOURCES OF THE BIGHORN BASIN, WYOMING.

By Cassius A. Fisher.

## INTRODUCTION.

This paper is the result of field work done during the seasons of 1904 and 1905 It is designed mainly to furnish information regarding geologic structure and. the prospects for underground water. The description of the formations of the Bighorn Mountain area is chiefly the work of N. H. Darton, under whose direction the exploration was made.

A general account of the surface waters is given, including a statement of their present and proposed uses for irrigation, and the economic products of a geologic nature are also described. The region considered comprises the Bighorn basin, a part of the Clark Fork basin, and the slopes of the adjoining mountain ranges, the entire area comprising 8,500 square miles. As shown on fig. 1, it is situated mainly in Bighorn County, in the northwestern part of Wyoming, and includes the greater portion of the area lying between meridians 107° 15′ and 109° 15′ and parallels 43° 40′ and 45°. It is bounded on the north by Montana, on the east by the Bighorn Mountains, on the south by Bighorn and Owl Creek mountains, and on the west by Shoshone, Absaroka, and Beartooth mountains.

## TOPOGRAPHY.

### GENERAL RELATIONS.

The area presents a great variety of topographic forms. Its salient feature is a broad structural valley bordered on nearly all sides by high mountain ranges. Along the outer portions of the valley there are a number of secondary ridges of moderate prominence, extending in a direction nearly parallel to the trend of the higher mountain ranges. The interior of the valley is characterized by high badlands slopes, which terminate in irregular ridges and sharp peaks or are capped by older gravel terraces. The streams crossing the basin flow in deep but broad, sloping valleys, bordered by terraces rising to adjoining highlands.

## RELIEF.

There is considerable range of altitude in the area. The highest point in the district is the Washakie Needles, very prominent peaks in the southern part of the Shoshone Mountains, which rise to an altitude of 12,496 feet. The lowest point is at the upper end of Bighorn Canyon, where the altitude is less than 3,600 feet above sea level. The average altitude for the interior of the basin is 5,000 feet.

*Bighorn Mountains.*—The high western slopes of the Bighorn Mountains extend diagonally across the eastern side of the district from southeast to northwest. In the northern part of the basin the slopes are 6 to 10 miles wide and extend from a point about 6 miles southeast of Shell post-office nearly to Medicine Mountain, where, owing to a decrease in dip, the high mountain front merges into a broad, sloping plateau that lies between the outer edge of the front range and the summit of the main uplift. The mountains generally rise abruptly from the plains to an altitude of about 8,000 feet and then more gradually toward the summit line or divide of the range, which reaches, in places, an altitude of about 10,000 feet. All the larger streams have their sources near the tops of the mountains and have cut

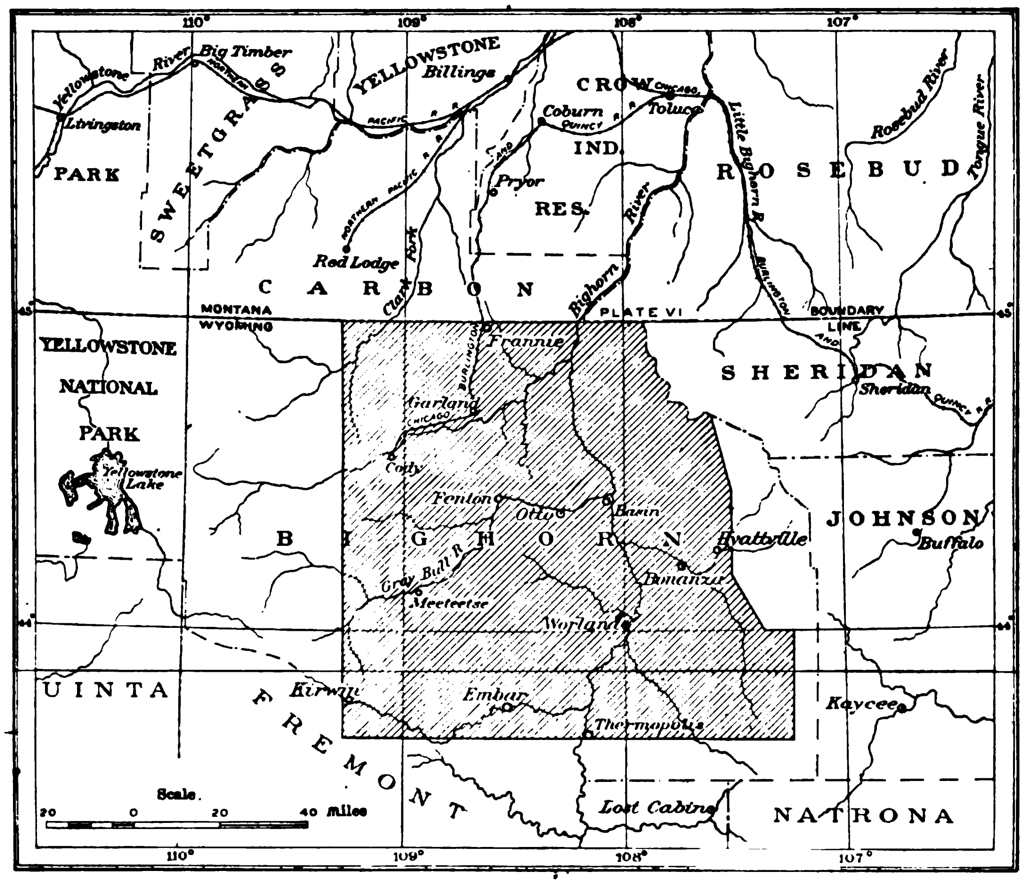

Fig. 1.—Map of part of Wyoming and Montana, showing area described.

*A.* CODY, FROM THE SOUTHEAST.

*B.* GRAY BULL RIVER ABOVE PITCHFORK RANCH, WYO.

deep canyons in the mountain front, while at its northern end the high, sloping plateau is deeply trenched by Bighorn River and Devil Canyon. There are a number of prominent peaks along the summit of the Bighorn Mountains, including Hunt, Little Bald, Bald, Medicine, and Duncom mountains, all of which rise to an altitude of about 10,000 feet.

From the summit of the high divide between Shell and Paintrock creeks southward the western side of the Bighorn Mountains is characterized by long, gradual slopes, generally deeply cut by the numerous mountain streams which traverse them. Extending along the base of the mountains from northwest to southeast are a number of minor folds, some of which give rise to prominent topographic ridges.

*Bridger and Owl Creek mountains.*—The Bighorn basin is bounded on the south by the Bridger and Owl Creek mountains. Both ranges belong to the same general uplift, which in reality is a prolongation of the Bighorn Mountains westward. The uplift ranges in altitude from 7,000 to 9,500 feet. Near the center from east to west it is crossed by Bighorn River, which cuts a narrow gorge having a depth of 2,250 feet in the axis of the range. The uplift is characterized on the north by long, gradual slopes and on the south by steep ascents, which are considerably faulted. Only the lower portion of the northern slope of that part of the uplift lying west of Bighorn River is included in the area to which this report relates. Along the northern side of Owl Creek Mountains, in the vicinity of Thermopolis, there are a number of small anticlines, giving rise to prominent topographic ridges.

*Absaroka and Beartooth mountains.*—The eastern side of the Absaroka and Beartooth mountains forms a narrow strip along the western margin of the district, extending from Black Mountain northward to the Montana line. The highest portion of this front range is Black Mountain, which has an altitude of about 8,600 feet above sea level. Across Shoshone River, in the vicinity of Cody, there is an anticlinal spur extending from the Absaroka Mountains, which comprises the Rattlesnake and Cedar Mountain uplift. The highest portion of this spur is near the north end of Rattlesnake Mountain. The uplift has been deeply trenched at the south end by Shoshone River, which has there formed a canyon that now separates Cedar and Rattlesnake mountains. Heart Mountain, an isolated butte in the northwestern part of the basin, is a very prominent topographic feature, rising to an altitude of nearly 8,000 feet. A view of Cody, in the Shoshone Valley, with Heart, Rattlesnake, and Cedar mountains in the distance, is shown on Pl. I, *A*. McCulloch Peak is a prominent eminence southeast of Heart Mountain, on the opposite side of Shoshone River. Its altitude is about 6,000 feet. Between Heart Mountain and McCulloch Peak and the main uplift west of these high points are several low ridges, due to minor folding, and along the base of the mountains lie a number of hogback ridges.

*Shoshone Mountains.*—From Shoshone River southward the basin is bordered by the Shoshone Mountains. This range, in appearance, is that of a high, deeply dissected plateau, presenting a confused mass of castellated peaks and ridges and traversed by many deeply cut canyons. This configuration is maintained to the eastern mountain front, which, in the region north of Gray Bull River, is bordered by a broad belt of low foothills. To the south of this stream the transition between mountain and plain is more gradual, and between Sunshine post-office and Dent's ranch many of the prominent mountainous ridges extend far out into the basin province.

*Sheep Mountain region.*—Several high ridges extend across the eastern side of the basin from the mouth of Shell Creek to Shoshone River, the most prominent of which are Sheep and Little Sheep mountains. Sheep Mountain has an altitude of about 5,000 feet, rising 800 to 900 feet above the surrounding country. It is deeply cut by Bighorn River in Black Canyon. Little Sheep Mountain has an altitude of about 5,000 feet, and, as it is bordered on the north and the east by lowlands, is a prominent topographic feature.

*Bighorn basin region.*—Between Clark Fork and Bighorn River there is a ridge extending from the vicinity of Heart Mountain northeastward to the western end of Pryor Mountain; the lowest point in this ridge, which is at the head of Big Sand Coulee, has an altitude of 4,800 feet. At the southwest end of the ridge the divide is very narrow, but to the northeast it is continued as a broad plateau which constitutes one of the most prominent topographic features of the northern part of the Bighorn basin. On either side of Clark Fork the surface rises gradually toward the surrounding highlands. To the west of Clark Fork, between the valley and the high mountains, there are a number of prominent hills, some of which have an altitude of nearly 7,000 feet. On the northern side of Sage Creek, from Frannie to beyond Cowley, the surface rises gradually toward the hogback ridges bordering the base of Pryor Mountain. Between Cowley and Garland there is a series of low, irregular, sandstone hills separated by wide, shallow valleys leading to Shoshone River. West of Garland, between Shoshone River and the base of the high plateau to the north, there is a broad, level area, comprising about 100 square miles, known as Garland Flats.

The region between Shoshone River and Dry Creek is made up of gradual slopes, traversed by high ridges and deep ravines. The divide between these two streams usually presents a high escarpment to the north and long, gradual slopes to the south. In its westward extension it terminates in McCulloch Peak. Beyond Dry Creek, which flows through a wide, open valley, there is a high terrace, more or less dissected by ravines on either side, which continues to the Gray Bull Valley. Northwest of Wise there is a high plateau sloping eastward, known as Meeteetse rim, which rises to an altitude of over 7,000 feet. It is about 3 miles wide and occupies the area between Meeteetse Creek and the head of Sage Creek. In its eastward extension it spreads out considerably and is traversed by numerous deep ravines. A very prominent ridge occurs between the headwaters of Dry and Sage creeks, which is locally known as Frost Ridge. It has an altitude of about 7,000 feet and continues from Frost ranch southeastward for about 6 miles.

The Gray Bull River Valley below Fourbear post-office is relatively wide, but in the vicinity of Pitchfork ranch it narrows rapidly and is bordered on either side by high bluffs of Cretaceous formations. Below Fenton the bluffs recede and the valley again widens to 5 or 6 miles and maintains this width nearly to the mouth of the river.

The topographic features of that portion of the basin lying between Gray Bull and Bighorn rivers are mainly those of a badlands district. Broadly viewed, the surface is a plain rising from east to west, which has been much dissected by large, intermittent streams and their numerous tributaries. A number of high buttes still remain in the interior of the basin. Tatman Mountain, Squaw Buttes, and Ilo Ridge are among the most prominent, all of which rise to an altitude of about 6,000 feet. To the west the surface rapidly rises, and a number of very prominent ridges occur between the headwaters of Owl, Cottonwood, Grass, and Gooseberry creeks and Wood River.

The region lying east of Bighorn River, which comprises the southeastern part of the basin, is mainly a badlands district. It consists of long, gradual slopes terminating in irregular ridges and sharp peaks. Along the high divide between No Wood and No Water creeks are a number of isolated peaks which have altitudes of 5,800 to 6,000 feet. On the west side of this divide, near the head of the east fork of No Water Creek, there is an area of very rugged topography, known as the Honeycombs.

## DRAINAGE.

*Bighorn River.*—The principal stream of the district is Bighorn River. It enters the area at Thermopolis and flows in a northerly direction across the region, passing into Bighorn Canyon near the Montana line. Its largest tributaries from the west are Shoshone and Gray Bull rivers and Gooseberry, Meeyero, and Owl creeks, and from the east No Wood and Shell creeks. A number of small streams of moderate flow enter the river in the northern part of the basin. These are Bear, Crystal, Five Springs, Willow, and Cottonwood creeks from the east and Crooked Creek from the west. There are several intermittent streams with large drainage areas in the central portion of the basin, which, during the flood season, carry a large volume of water. The largest of these are Dry, Dry Cottonwood, Kirby, and No Water. Measurements of the flow of Bighorn River have been taken at Thermopolis and Basin, and the results of these observations are given in the following table:

*Discharge measurements of Bighorn River at Thermopolis, Wyo.*

[Made by A. J. Parshall.]

| 1899. | Second-feet. |
|---|---|
| July 28 | 4,867 |
| August 7 | 4,204 |
| August 16 | 2,673 |
| September 14 | 1,162 |
| 1900. | |
| May 28 | 8,500 |
| May 29 | 10,527 |
| May 30 | 12,187 |
| September 13 | 945 |
| September 18 | 672 |
| 1902. | |
| June 11 | 9,080 |
| June 14 | 8,391 |
| June 16 | 6,334 |
| 1903. | |
| March 27 | 621 |
| May 23 | 1,953 |
| May 25 | 1,709 |
| June 20 | 9,280 |
| June 21 | 8,444 |
| June 22 | 7,442 |
| July 18 | 3,882 |
| July 20 | 4,024 |
| 1904. | |
| March 25 | 290 |
| June 19 | 12,940 |
| June 22 | 14,240 |
| July 11 | 7,117 |
| July 12 | 7,467 |
| July 17 | 6,130 |
| July 28 | 5,008 |
| August 3 | 3,941 |
| August 11 | 2,878 |
| August 26 | 2,084 |
| November 24 | 438 |

*Shoshone River.*—Shoshone River, the largest tributary of Bighorn River, flows diagonally across the northern portion of the Bighorn basin. It is formed by the North Fork and the South Fork of the Shoshone, which have their confluence just above Shoshone Canyon. This river was formerly called Stinkingwater River, a name derived from the distinctly sulphurous odors which its waters emit, especially in the vicinity of Cody, where there are a number of hot mineral springs (Pl. XVI, *A*, p. 60). The principal tributaries of Shoshone River are, from the south, Carter, Diamond, Sulphur, Sage, Whistle, and Coon creeks, and from the north, Trail, Dry, Cottonwood, Eaglenest, Alkali, and Sage creeks. Nearly all these streams are dry for a portion of the year. Discharge measurements of Shoshone River near Cody, Wyo. (see Pl. II, *A*), have been made as follows:

*Discharge measurements of Shoshone River near Cody, Wyo.*

| 1902. | Second-feet. | 1903. | Second-feet. |
|---|---|---|---|
| April 26 | 538 | June 24 | 4,212 |
| June 7 | 4,352 | July 14 | 3,829 |
| July 17 | 2,812 | July 15 | 3,299 |
| July 31 | 2,039 | July 25 | 3,087 |
| December 8 | 270 | October 31 | 450 |
| 1903. | | 1904. | |
| March 20 | 263 | March 29 | 253 |
| April 21 | 633 | April 30 | 1,536 |
| April 25 | 1,399 | May 22 | 6,200 |
| May 19 | 1,374 | June 17 | 6,330 |
| May 20 | 1,263 | June 20 | 9,116 |
| June 6 | 2,624 | August 27 | 1,186 |
| June 11 | 5,502 | September 9 | 885 |
| June 16 | 7,297 | October 8 | 413 |
| June 17 | 8,885 | December 22 | 321 |
| June 18 | 8,840 | | |

Hydrographer, A. J. Parshall, except for the following dates: June 6, 11, and October 31, 1903, and May 22, June 17, 20, August 27, October 8, and December 22, 1904, J. Ahern; April 30, 1904, W. E. Young.

*Gray Bull River.*—This stream rises in the Shoshone Mountains and flows northeastward across the central part of the basin, joining Bighorn River near Coburn post-office. As the stream has its source high on the slopes of a snowy range, it carries a large amount of water, especially in midsummer. At Meeteetse its flow is estimated as follows:

*Estimated monthly discharge of Gray Bull River at Meeteetse, Wyo., 1897.*

| | Second-feet (mean). | | Second-feet (mean). |
|---|---|---|---|
| June 14–30 | 943 | October | [a]100 |
| July | 513 | November | [a]100 |
| August | 299 | December | [a]100 |
| September | 104 | | |

[a] Approximate.

The largest tributary is Wood River, which rises high on the slopes of the southern part of the Shoshone Mountains at altitudes ranging from 10,000 to 12,000 feet, where there is much snow and a moderately high rainfall. In consequence this stream carries a good volume of water. From the north, Gray Bull River

*A.* SHOSHONE RIVER AT CODY, WYO.

*B.* SHOSHONE DAM SITE.

Upper end of Snoshone Canyon

receives small flows from Rawhide, Spring, and Meeteetse creeks, and from the south, from Timber and Franks creeks.

*Clark Fork.*—This stream crosses the extreme northwest corner of the district. It rises high in the slopes of the Absaroka Mountains to the west and carries a large volume of water, especially during the early summer months. From the south, its principal tributaries are Pat O'Harra, Paint, and Newmeyers creeks and from the west, Little Rocky, Bennett, and Line Creeks. All these streams have a vigorous flow derived from springs on the mountain slopes.

*Other important streams.*—Owl Creek, which flows along the base of the Owl Creek Mountains and joins Bighorn River below Thermopolis, carries only a moderate volume of water, which probably does not exceed 20 second-feet. It is formed by North Fork and South Fork of Owl Creek, which have their confluence near Embar ranch.

In the southwestern part of the basin along the base of the Shoshone Mountains several streams have their sources. Gooseberry Creek, the largest of these, flows across the southern part of the basin and joins Bighorn River above Olwen post-office. It carries considerable water in its upper course, and a small amount goes through to Bighorn River at all seasons of the year. Middle and Enos creeks, two small running streams, join Gooseberry Creek in the vicinity of Dickie ranch.

Meeyero Creek, which drains the district between Gooseberry and Owl creeks, is formed by Grass and Cottonwood creeks, at a point about 6 miles east of Morrison ranch, and joins Bighorn River near Winchester post-office. Cottonwood and Grass creeks are fed by springs at the base of the mountains and have small flows which continue throughout the year, but below their junction the water sinks, and the lower part of Meeyero Creek is usually dry in the late summer months.

No Wood Creek flows in a northwesterly direction along the west side of the Bighorn Mountains and receives several vigorous mountain streams, most of which rise in springs in the higher slopes of the Bighorn Mountains east of the area here described. The principal affluents are Paintrock and Tensleep creeks, and above these are Spring, Otter, and Little Canyon creeks. All of these are flowing streams, which add materially to the volume of No Wood Creek. Messrs. Elwood Mead and C. T. Johnston made a discharge measurement of No Wood Creek at Morgan's ranch, 4 miles above its mouth, August 21, 1897, which showed a flow of 109 second-feet.

Shell Creek, one of the largest branches of Bighorn River in the northeastern part of the area, rises in the Bighorn Mountains near the base of Cloud Peak, in a region of perpetual snow. It has an average fall of 20 feet a mile in the lowlands west of the mountains and carries a large amount of water. Trapper, Horse, and Beaver creeks are its principal tributaries.

Dry Cottonwood Creek is the largest intermittent stream in the central part of the Bighorn basin. It rises in the high hills near Meeteetse and joins the Bighorn at Worland. The area drained by this stream is about 450 square miles, lying between Gray Bull River and Gooseberry Creek. As this stream has its source on the west side of the basin, where there is a relatively large rainfall, it carries considerable flood water. Dry Creek, another important intermittent tributary, crosses the north-central part of the basin, rising near Meeteetse rim and joining Bighorn River at Coburn post-office. This stream also has a large watershed.

The southeastern part of the Bighorn basin is drained by Kirby and No Water creeks, but these streams do not rise high on the slopes of the adjoining mountains, where they can receive water from melting snows, and in consequence are flowing streams for part of the year only. The region which they drain is used mainly for grazing.

## OUTLINE OF THE GEOLOGY.

### STRATIGRAPHY.

The formations appearing at the surface within the area to which this report relates consist of both igneous and sedimentary rocks. They are representatives of the pre-Cambrian, Cambrian, Ordovician, Carboniferous, Triassic, Jurassic, Cretaceous, Tertiary, and Quaternary systems. The distribution of the various formations, except the Quaternary, is shown on the geologic map (Pl. III, pocket), and their structural relations are indicated in the cross sections (Pl. IV). The data for the geologic map of the area included in R. 102 and 103 W., T. 43 and 44 N., have been taken from the report on the geology of the Owl Creek Mountains by Mr. N. H. Darton.[a]

The following table shows the order, age, and characteristic features of the formations (Pl. V):

*Table of geologic formations in the Bighorn basin.*[b]

| System. | Formation. | Principal characters. | Thickness. |
|---|---|---|---|
| | | | *Feet.* |
| Quaternary | Alluvium | Sand, loam, and gravel | 20–40 |
| | Hot spring deposits | Light-colored calcareous rock | 20 |
| | Later terrace gravels | Gravel and sand; dark color due to large amount of volcanic material. | 20–30 |
| | Early terrace gravels | Sand, gravel, and sandy clay; dark pebbles predominate in gravel. | 20–60 |
| | Volcanic rocks | Mainly volcanic breccia with basalt flows, intrusive dikes, and associated sedimentary rocks. | ........... |
| Tertiary | Wasatch | Sand, clay, and conglomerate | 2,000–3,000 |
| Cretaceous | Laramie and associated formations. | Alternating layers of sandstone and shale, containing coal, greenish-gray sandstones at base. | 5,000–7,000 |
| | Pierre shale | Dark sandy shales containing concretions of iron | 1,200–2,000 |
| | Colorado formation | Dark gray to black shales, with sandstone, clay, and concretionary layers. | 1,400–2,000 |
| | Cloverly formation | Buff sandstones, alternating with massive red to purple shales. | 200–300 |
| | Morrison | Pale grayish-green sandstones and shales | 130–400 |
| Jurassic | Sundance | Greenish-gray shales and sandstones, with layers of limestone. | 200–350 |
| Triassic (?) | Chugwater formation | Massive red sandstone and shale, with layers of limestone and gypsum. | 600–800 |
| Carbeniferous | Embar formation | Massive gray limestone | 80–200 |
| | Tensleep sandstone | Massive gray sandstone, containing layers of limestone | 30–250 |
| | Amsden formation | Red sandy shales and sandstones, with layers of limestone and chert. | 100–200 |
| | Madison limestone | Gray massive limestones | 700–1,000 |
| Ordovician | Bighorn limestone | Siliceous gray limestone, very hard and massive | 200–300 |
| Cambrian | Deadwood formation | Sandstone, shale, conglomerate, and limestone | 700–1,500 |
| Pre-Cambrian | .......................... | Granite | .......... |

---

[a] Geology of the Owl Creek Mountains, etc., U. S. Senate Doc. No. 119, 59th Cong., 1st session.

[b] Many of the names given in this table have been proposed by N. H. Darton for the Bighorn Mountain region. They are defined in a Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range: Bull. Geol. Soc. America, vol. 15, 1904, pp. 379–448, pls. 23-34.

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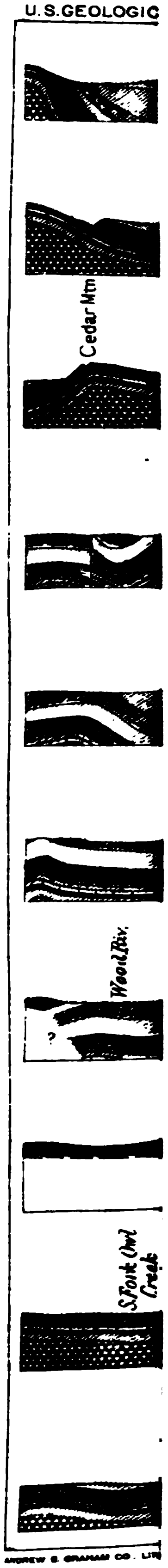

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## PRE-CAMBRIAN ROCKS.

### GRANITE.

*General statement.*—The underlying formation of the Bighorn uplift is a massive granite which has been raised several thousand feet above its original position. In the northern part of the Bighorn Mountains the overlying sedimentary rocks conceal the greater part of the granite, but it appears in irregular areas in several portions of the district. The most extensive exposures are about Bald Mountain, in the anticline extending from Red Gulch to a point west of Medicine Mountain, in the valley of Porcupine Creek, in Cookstove basin, and in the deeper portions of the canyons of Shell Creek. The rock is generally very massive and is of pre-Cambrian age. Granite is also exposed in Shoshone Canyon and on the north slope of the Owl Creek Mountains.

*Granites of the Bighorn Mountain region.*—The granites of the northwestern portion of the Bighorn Mountains are mainly a coarse-grained red variety, but there are a few small areas of a fine-grained gray granite.

The so-called red granite has a light-grayish appearance at a distance, but when viewed at close range is seen to be characterized by a more or less pronounced reddish tinge, due to the abundance of pink feldspar in it. The rock often presents a well-defined system of joints. and weathers into bold, rounded forms. Its surface is usually rough, owing to differential weathering, and the large feldspar phenocrysts often have sufficient prominence to give it a porphyritic appearance. The principal constituents are feldspar, quartz, and mica, occurring in varying proportions.

The gray granites of the district are generally uniform in color and texture and in the kind, amount, and distribution of their component minerals. There are, however, local areas where the ferromagnesian minerals predominate, giving the rock a very dark appearance. The gray granite presents in some localities a well-defined system of joints, the rock weathering into angular blocks or slabs, making the topography very rugged. To the unaided eye this rock is of dark-gray color, of medium to fine texture, and is marked occasionally by lines of secondary movement. The principal constituents are feldspar, quartz, and biotite.

*Dikes of the Bighorn Mountain region.*—Several dikes of diabase and peridotite cut the granite area described above. They vary in width from 2 to 25 feet and usually extend transversely or at a wide angle to the major axis of the main uplift. These dikes, owing to the greater hardness of the rock, offer greater resistance to atmospheric agencies than the softer granites into which they have been intruded, and consequently stand out in more or less prominent ridges that extend across the granitic areas. The rock weathers into cubes 2 to 6 inches square, the ultimate product of decomposition being a reddish-brown residual soil which in color presents a striking contrast to that derived from the lighter colored country rock. There are several of these dikes in the vicinity of Bald Mountain and on Porcupine and South Beaver creeks. In the granite flats west of Bald Mountain there is a branch dike extending north-northwest. It passes east of Medicine Mountain under the Deadwood sandstone for about a mile and appears to be continued due northward by one of the dikes crossing Porcupine Creek, its entire length being at least 5 miles. Small dikes, or chimneys, of diabase appear in the vicinity of Fortunatus Mill, especially to the southwest. They are from 10 to 20 feet in diameter and of circular or elliptical outline. These smaller masses are of variable character and some of them exhibit considerable mineralization. The distribution of the dikes is not shown on the geologic map.

A microscopic examination of the diabase shows that the constituent minerals are feldspar, augite, and quartz, with biotite, magnetite, chlorite, and apatite occurring in smaller amounts.

*Granite and diabase of Rattlesnake Mountain.*—A small area of granite is exposed in Shoshone Canyon between Rattlesnake and Cedar mountains. The rock is moderately coarse grained and massive and appears to have been subjected to considerable pressure, for in places it is schistose. It has a well-defined system of joints, and weathers into bold, rounded forms. The granite is cut by dikes and sills of a quartz-bearing diabase. No microscopic examination of the granite of this locality has been made. One of the diabase dikes is shown in Pl. VI, *B*, p. 12.

*Granite of Owl Creek Mountains.*—The granites of the north slope of the Owl Creek Mountains, a small area of which is exposed within the district, appear to have no essential variation from those above described.

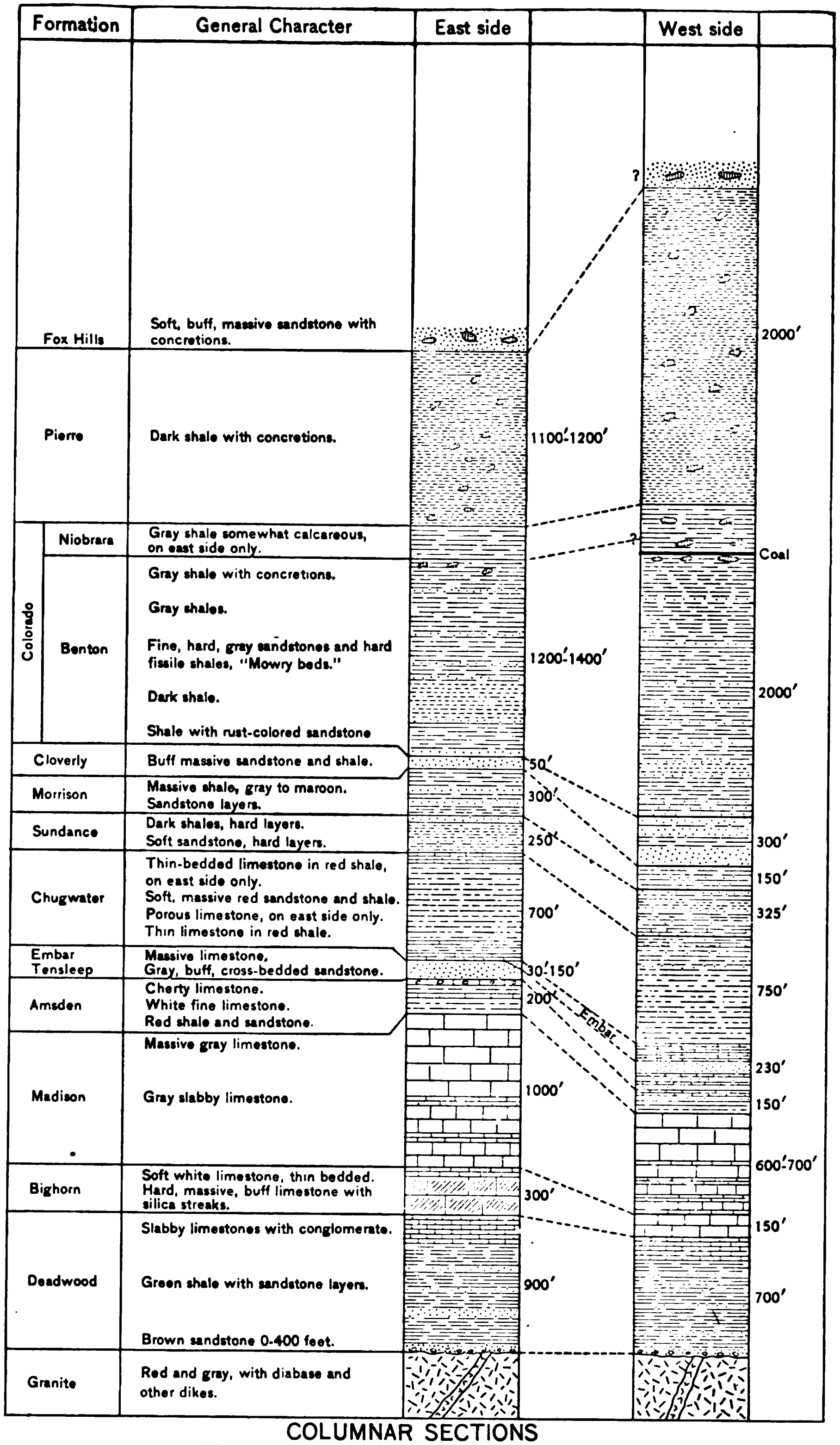
## CAMBRIAN SYSTEM.

### DEADWOOD FORMATION.

*General relations.*—The oldest sedimentary formation outcropping within the area is a series of beds of sandstone, shale, limestone, and conglomerate of middle Cambrian age that have a thickness ranging from 700 to 1,500 feet. To these beds, in the Bighorn Mountain province, Mr. Darton has applied the name Deadwood formation. The basal member is a sandstone, somewhat conglomeratic, lying on the granite. Its thickness varies from 10 to 30 feet. Next above this is a series of greenish-gray shales with layers of sandstone and sandy shale, having in all a thickness of about 300 feet. This member is succeeded by a sandstone 25 to 40 feet thick, which in turn is overlain by several hundred feet of shale containing thin-bedded conglomeratic sandstones and limestones. Overlying these beds are alternating layers of limestone and limestone conglomerate made up of flat limestone pebbles. The pebbles are mostly green in color, but on freshly broken surfaces are gray to pale pink. These limestones and conglomerates have a thickness of about 200 feet and are sometimes capped by a layer of white sandstone, which is regarded as the base of the Bighorn formation.

Fossils have been observed at various horizons, chiefly in the limestones a short distance above the middle of the formation, in the sandstones next below, and in the basal sandstones. The prominent forms are *Dicellomus politus* and *Ptychoparia owenia*, the latter occurring mainly in the basal sandstone.

*Absaroka Mountain region.*—In Shoshone Canyon on the western side of the district the entire succession of beds comprising the Deadwood formation is exposed. The limits of the formation here are well defined, but the thickness is somewhat diminished. At the top there is a thin-bedded limestone alternating with layers of green shale and flat-pebble conglomerate; below this occur sandstone and shale in



| Formation | | General Character | East side | |
|---|---|---|---|---|
| Fox Hills | | Soft, buff, massive sandstone with concretions. | | |
| Pierre | | Dark shale with concretions. | | 1100'-1200' |
| Colorado | Niobrara | Gray shale somewhat calcareous, on east side only. | | |
| | Benton | Gray shale with concretions.<br>Gray shales.<br>Fine, hard, gray sandstones and hard fissile shales, "Mowry beds."<br>Dark shale.<br>Shale with rust-colored sandstone | | 1200'-1400' |
| Cloverly | | Buff massive sandstone and shale. | | 50' |
| Morrison | | Massive shale, gray to maroon.<br>Sandstone layers. | | 300' |
| Sundance | | Dark shales, hard layers.<br>Soft sandstone, hard layers. | | 250' |
| Chugwater | | Thin-bedded limestone in red shale, on east side only.<br>Soft, massive red sandstone and shale.<br>Porous limestone, on east side only.<br>Thin limestone in red shale. | | 700' |
| Embar<br>Tensleep | | Massive limestone.<br>Gray, buff, cross-bedded sandstone. | | 30'-150' |
| Amsden | | Cherty limestone.<br>White fine limestone.<br>Red shale and sandstone. | | 200' |
| Madison | | Massive gray limestone.<br>Gray slabby limestone. | | 1000' |
| Bighorn | | Soft white limestone, thin bedded.<br>Hard, massive, buff limestone with silica streaks. | | 300' |
| Deadwood | | Slabby limestones with conglomerate.<br>Green shale with sandstone layers.<br>Brown sandstone 0-400 feet. | | 900' |
| Granite | | Red and gray, with diabase and other dikes. | | |

COLUMNAR SECTIONS
EAST AND WEST SIDES BIGHORN BASIN
By C. A. FISHER

Scale

0 500 1000 2000 feet

1905

alternate succession, and at the base is a coarse conglomeratic sandstone about 50 feet thick lying unconformably on the granite. The formation has a thickness of about 700 feet and is overlain by the massive limestones of the Bighorn formation. It is exposed also along the crest of Rattlesnake Mountain.

*Bighorn Mountain region.*—The higher portion of the northern part of the Bighorn Mountain Range consists of sandstones and shales of the Deadwood formation. These rocks have a thickness of about 900 feet and, owing to the large amount of soft material, are weathered into long, gradual slopes. This feature is well illustrated in Bald Mountain, which rises as a huge, rounded mound about 800 feet above a floor of granite. Little Bald Mountain is similar in shape, but somewhat smaller. In Medicine, Duncom, and Hunt mountains there are long slopes of Deadwood shales capped by the harder Bighorn limestone. The Deadwood beds are also extensively exhibited in the valleys of Cedar and Shell creeks. While the total thickness of the formation is generally as much as 900 feet, it appears to be somewhat less than this about Medicine Mountain; but, on the other hand, it thickens locally to nearly 1,500 feet in the lower portion of Shell Creek Canyon. Owing mainly to its hardness the basal sandstone is in most places a prominent feature. It is a reddish rock, coarse grained, often conglomeratic at base, massively bedded and in part cross-bedded, with a thickness varying from 20 to 50 feet. It lies on a smooth surface of granite, planed by early Cambrian erosion. This smooth surface is noticeable around Bald Mountain, especially in places where the sandstone has been recently removed. In the vicinity of Fortunatus Mill and the old Bald Mountain settlement the basal Deadwood conglomerates occupy the surface and are in places disintegrated into beds of bowlders and gravel which carry small values in free gold. In portions of the region about Bald Mountain the basal sandstone is a 4-foot layer of deep-red, coarse-grained, often pebbly sandstone. It is overlain by a 5-foot bed of red-brown conglomerate composed of quartz pebbles and from 5 to 10 feet of pale buff sandstone containing red streaks. In the region along Shell Creek the shales usually lie directly on the granite. Some of the sandy layers of the formation contain a green, granular mineral (glauconite). Toward the top of the formation there is about 200 feet of limestone which breaks easily into slabs and is gray to pinkish in color. This contains layers of limestone conglomerate characteristic of the horizon. This rock consists of flat to subangular limestone pebbles intermingled with broken and distorted layers of limestone, with a matrix of fine limestone and shale material. Most of the pebbles are so thickly covered with grains of glauconite that they have a greenish color, but like the associated beds are gray or pinkish on freshly broken surfaces. They are intraformational conglomerates.

On many of the steep slopes of the Deadwood formation there are extensive landslides which have on their surfaces large blocks of Bighorn limestone. These slides are caused by the softness of the Deadwood shale, which, when saturated with water, is unable to bear a heavy load. They occur along the canyons of Shell and Cedar creeks, in the Bighorn Mountains, as well as on both sides of Shoshone Canyon, in the region to the west.

*Owl Creek Mountain region.*—The Deadwood formation outcrops in 3 small areas along the southern margin of the district in the vicinity of Anchor, but the beds here present no unusual features.

## ORDOVICIAN SYSTEM.

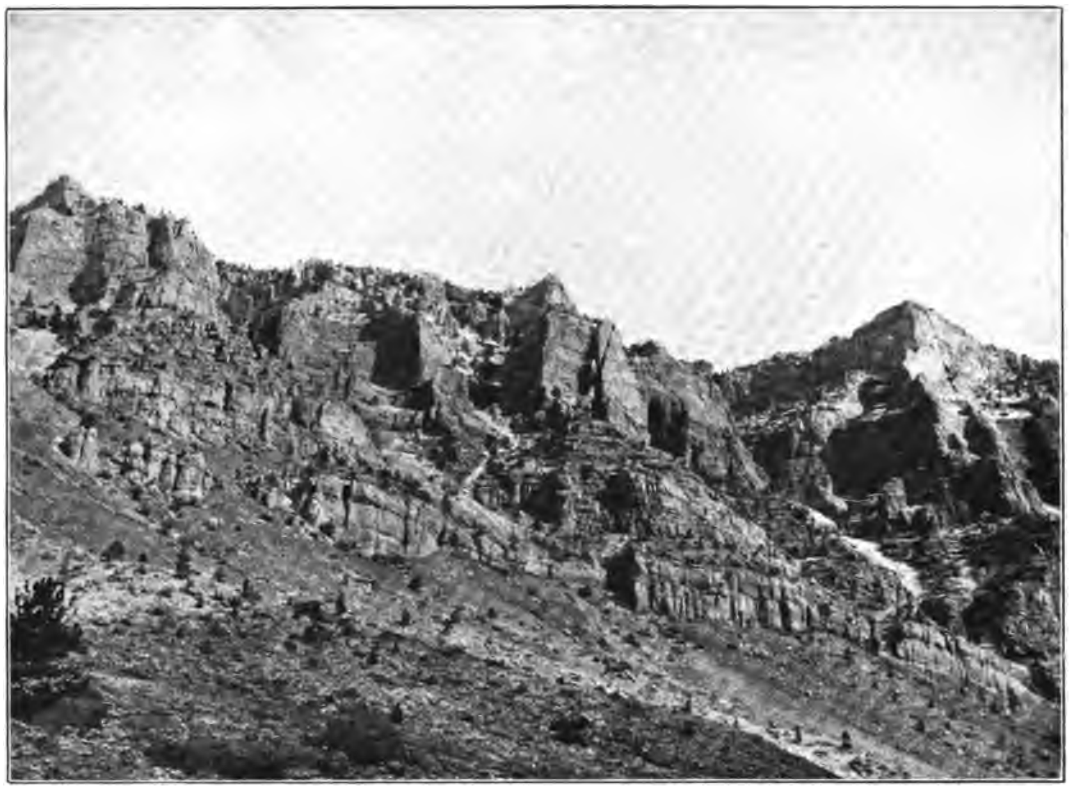
### BIGHORN LIMESTONE.

*General relations.*—The Bighorn formation is one of the most prominent members of the great limestone series constituting the front ranges of the Bighorn, Absaroka, and Owl Creek mountains. It has a thickness of about 250 feet and outcrops everywhere in a prominent escarpment overlooking the softer shales of the Deadwood formation. The distribution of the formation is shown on the geologic map. It consists mainly of massive limestones, generally of light-gray to buff color, containing a reticulating network of silica which causes the limestone on weathering to assume a pitted or honeycombed appearance. The formation does not contain a large number of fossils, but those which have been found are of late and early Ordovician age.

*Absaroka Mountain region.*—The Bighorn limestone is exposed in all the deep canyons cut by the larger streams on the western side of the district in the front range of the Absaroka Mountains and on the west face of the higher portion of Rattlesnake Mountain. In Shoshone Canyon the formation is about 150 feet thick, presenting high, straight escarpments above the slopes of softer Deadwood shales on either side of Shoshone River. The limestone at this place has its usual massive character, but the characteristic reticulation appearing on the weathered surfaces of the rock is not so pronounced. The upper portion of the formation consists of thin-bedded limestone. There is no notable unconformity between these and the limestones of the Madison formation. The Bighorn limestone outcrops in the canyons of Clark Fork and Pat O'Harra, Little Rocky, Bennett, and Line creeks in the region west of the area to which this report relates. Whether the beds lying immediately above the typical Bighorn limestone in Shoshone Canyon include sediments of Silurian and Devonian age was not ascertained, for no fossils were observed in them. In the Crandall quadrangle, northwest of the Bighorn area, the Jefferson and Three Forks limestones, described by Mr. Hague, lie between the Cambrian and Carboniferous rocks. The Jefferson limestone probably includes the Bighorn limestone, and possibly higher beds also. The Three Forks limestone is of Devonian age.

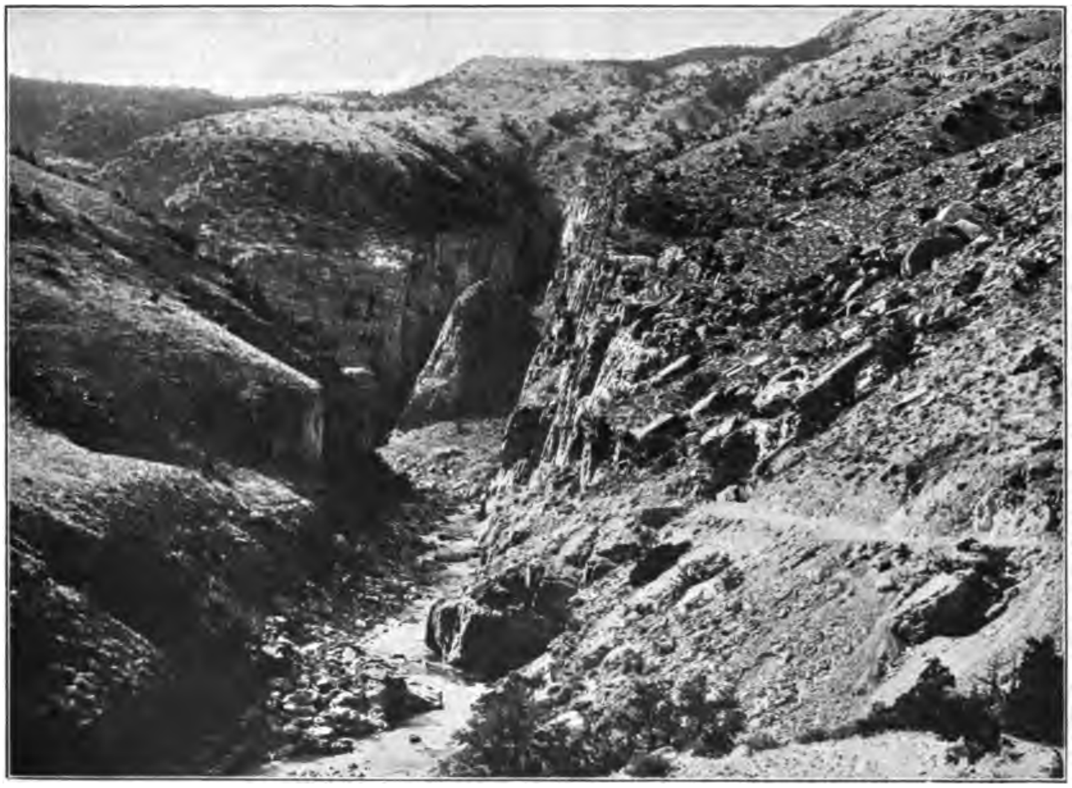
*Bighorn Mountain region.*—In the northern portion of the Bighorn Mountains the Bighorn limestone is the most conspicuous sedimentary formation. Here also it is a hard, massive limestone which outcrops in thick ledges lying on long slopes of Deadwood rocks. Its thickness averages 300 feet, including an upper portion of 100 feet of soft, thin-bedded limestone, which is regarded as a part of the formation mainly because of its Ordovician age. The principal exposures of the Bighorn limestone form cliffs on the higher slopes of the mountains, capping some of the prominent ridges north of Bald Mountain and bordering the sides of the valleys of Shell, West Pass, and Porcupine creeks. In Hunt Mountain this limestone presents a high, straight escarpment facing the west, which can be seen far out in the Bighorn basin. The formation is cut by faults on either side of South Beaver Creek and for some distance north of Devil Canyon. In the mouths of the canyons of Cottonwood, Five Springs, and Horse creeks small exposures occur.

The limestone constituting the greater part of the Bighorn formation is usually of light-buff color, weathering somewhat darker, and containing the coarse matted



*A.* CHARACTERISTIC WEATHERING OF BIGHORN LIMESTONE AND UPPER PART OF MADISON LIMESTONE.

North face of Shoshone Canyon.



*B.* DIABASE DIKE CUTTING GRANITE.

network of irregular masses of silica referred to above. This and the massive bedding are characteristic of the limestone throughout the Bighorn Range. Owing to the softness of the underlying Deadwood shale and the hard, massive nature of the Bighorn limestone, their exposure gives rise to high cliffs, having a talus of large blocks of limestone on the slopes below. In the canyons are close, high walls where streams cross the formation and high, vertical cliffs where the rock rises in the slopes. In its upper portion the formation consists of limestone that is softer and purer than that below; the bedding is thinner, the color is a lighter gray, and the rock in part is very compact or fine grained. There is considerable variation in the local features of the formation, and the thickness varies from 75 to 100 feet. In many places the upper member includes a bed of hard, massive limestone, with a network of siliceous material similar to the lower member, but not so pronounced in character and only about 30 feet thick; some beds of shale and limestone are also included. At the top the formation is not easily separated from the Carboniferous limestone. While the total thickness of the Bighorn formation averages 300 feet, it appears to be more than this in the lower part of Shell Creek Canyon, where two beds of massive, siliceous limestone occur in the upper portion, separated by slabby limestones. This upper portion is here separated from the basal by white, fine-grained limestone.

The greater part of the Bighorn limestone yields but few fossils. The lower massive member contains chiefly fragments of maclurinas and coral. In the lower portion of the upper limestone there is a horizon of corals consisting largely of *Halysites catenulatus*, while toward the top fossils of Richmond fauna occur in moderate numbers at localities to the east. The coral-bearing limestones underlie the higher massive bed of siliceous limestone, and the corals are often numerous and of large size. At a point east of Bald Mountain some beds of reddish shaly sandstone lie between the coral-bearing limestones and the great massive limestones below. Fossils were collected by Mr. Darton in the Bighorn limestone on top of Medicine Mountain from beds about 100 feet above the base of the formation. The following are the forms from this locality, as determined by Mr. E. O. Ulrich: *Streptelasma* sp. undet.; *Protarea* n. sp. (massive); *Plectorthis plicatella* (?); *Dinorthis pectinella*(?); *D. subquadrata*(?); *Rhynchotrema capax*(?) var.; *Oxydiscus*, sp. undet.; *Liospira*, sp. undet.; *Trochonema* sp. undet. (near *T. robbinsi*); *Holopea excelsa*(?); and *Huronia* sp. undet.—a lower Galena-Trenton fauna as nearly as can be ascertained. From the upper beds of the formation, at a point about 3 miles east of Bald Mountain cabins, the following fossils were collected: *Streptelasma* n. sp. with trilobite calyx; *Calapoecia* sp. undet.; *Favosites* sp. undet.; *Stromatocerium* (?) n. sp.; *Dalmanella testudinaria* var.; *Leptaena unicostata*, and *Rhynchotrema capax*.

## CARBONIFEROUS SYSTEM.

### MADISON FORMATION.

*General relations.*—The Madison formation constitutes the greater part of the high, anticlinal front range of the Bighorn, Absaroka, and Owl Creek mountains. It has a total thickness varying from 600 to 1,000 feet, and consists mainly of massive gray limestone. In the upper part there is a pure limestone which weathers into castellated forms (see Pl. VI, *A*). In the lower portion some of the beds are very sandy. The formation contains a Mississippian fauna.

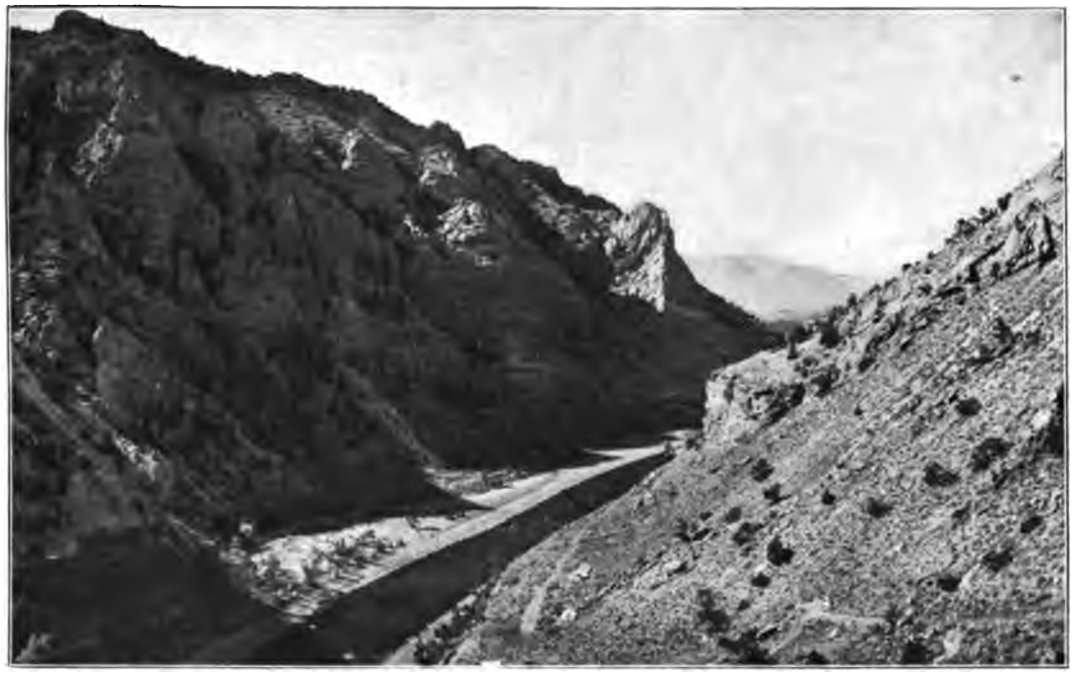
*Absaroka Mountain region.*—The Madison limestone is exposed in Shoshone Canyon, on the west side of the Bighorn basin, and high on the slopes of Rattlesnake, Black, and Heart mountains. In Shoshone Canyon the formation consists of a lower member, a massive, dark-gray limestone containing thin-bedded layers, and an upper member which is a lighter gray and somewhat softer limestone. Its total thickness ranges from 600 to 700 feet, and it yields fossils in moderate abundance. At Heart Mountain about 400 feet of limestone are exposed in the side of an isolated knob which rises to an altitude of nearly 8,000 feet. A large area is exposed on the higher slopes of Black Mountain, where it is deeply trenched by numerous small canyons. In the exposures on Clark Fork the formation consists of an upper and lower members, separated by thin-bedded limestones alternating with red shale.

*Bighorn Mountain region.*—Across the northeastern part of the basin, from near the mouth of Shell Creek to Lovell, extend a number of anticlines, the most conspicuous of which comprise Sheep and Little Sheep mountains. Bighorn River crosses both of these mountains, flowing through deep canyons. In these canyons and along the crests of the uplifts are exposures of Madison limestone.

Along the west side of the Bighorn Mountains, from Trapper Creek to the upper end of Bighorn Canyon, the limestone rises in rugged slopes 1,000 to 2,000 feet in height. It is deeply trenched by many canyons, of which the deepest are those of Shell and Horse creeks, where there are excellent exposures of all the beds. In the northeastern part of the district, between Bighorn River and the high mountain summits, the beds lie nearly horizontal in an area of approximately 40 square miles. Along Shell Creek the formation has been widely and deeply eroded and its edge rises in high cliffs on the southern side of the valley of that stream. From these cliffs a thick sheet of the limestone slopes gently down to the south and west, where it is deeply cut by White and Trapper creeks. The Madison limestone in this region consists of the usual two members, the lower one a somewhat massively bedded limestone in part of dark-gray color, and the upper about 200 feet thick, of softer, purer, and more massive rock, which weathers into the characteristic pinnacled forms. The base of the formation is not distinct, and, although between this and the succeeding Bighorn formation there is a hiatus representing Silurian and Devonian times, no unconformity is noticeable.

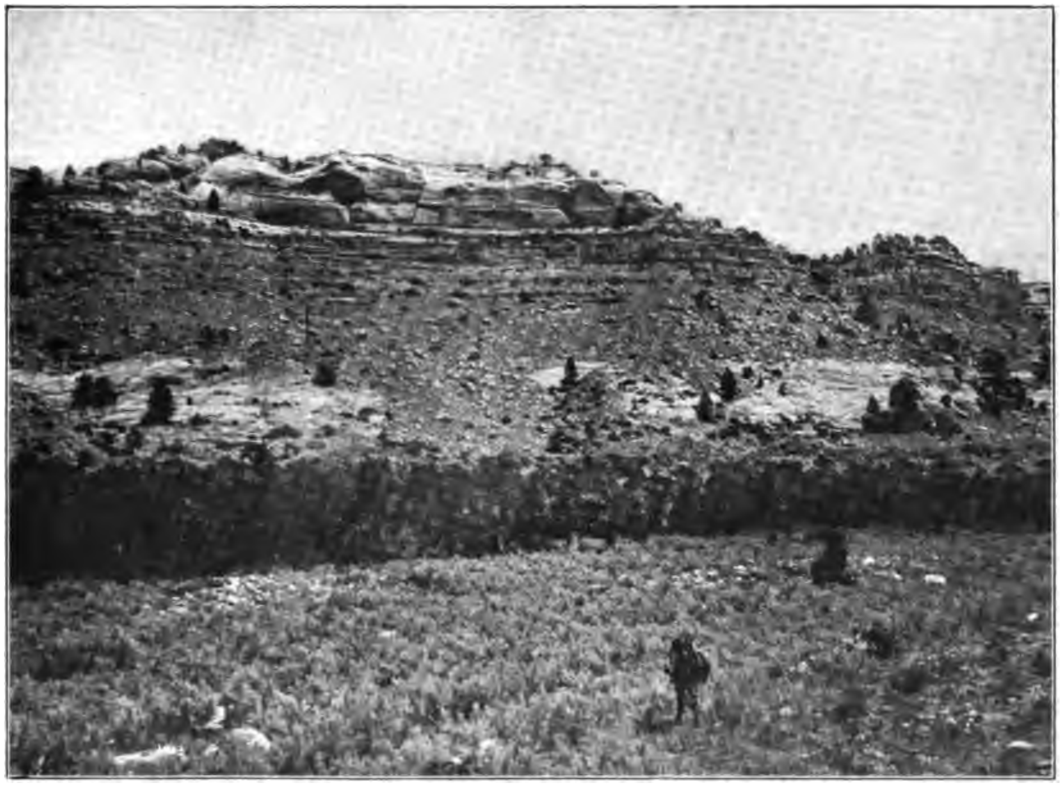
On the northern side of Shell Creek Canyon the following fossils were collected by Mr. Darton from the middle of the Madison formation: *Rhipidomella michelini, Spirifer centronatus, Seminula humilis, Eumetria verneuiliana, Orthotetes inæqualis, Syringothyris carteri* (?), and *Camerotoechia herrickana*, constituting a Madison limestone fauna, of Mississippian age.

*Owl Creek Mountain region.*—Exposures of Madison limestone occur along the northern side of the Owl Creek Mountains in the southwestern part of the district, but here the thickness is very much diminished, being represented by less than 600 feet of beds. In other respects the formation shows no material change.



*A.* MASSIVE BEDS OF MADISON LIMESTONE OVERLAIN BY SOFTER AMSDEN SHALES.

Upper end of Shoshone Canyon above dam site.



*B.* TYPICAL AMSDEN FORMATION.

Western slope of Bighorn Mountains.

### AMSDEN FORMATION.

*General relations.*—Overlying the Madison limestone and generally extending far up the outer slopes of the mountains, are limestones, shales, and cherts, constituting the Amsden formation. This has an average thickness of 150 feet; its lower portion consists of bright-red shale, 60 to 80 feet thick, often containing layers of limestone, and its upper portion of a thin-bedded sandy limestone, in part containing extensive deposits of chert. Fossils are not abundant, but some that have been collected by Mr. Darton from upper beds on the eastern side of the district are of Pennsylvanian age.

*Absaroka Mountain region.*—The Amsden outcrop extends nearly halfway across the district along the front range of the Absaroka Mountains. It occupies a wide area on the higher slopes of the Rattlesnake and Cedar Mountain Range. In the vicinity of Black Mountain the dips are steep and the formation does not extend far up the slopes, but farther north and west, in the low, sloping plateau, it is extensively exposed. On the south side of Clark Fork Canyon, where the beds dip steeply, the formation is composed of a basal member of red sandy shale 75 feet thick, overlain by a series of alternating beds of gray sandstone, chert, and fine-grained slabby limestone.

In Shoshone Canyon (Pl. VII, *A*) the formation contains the usual red sandy layer at the base, followed in ascending order by harder beds of sandstone, quartzite, limestone, and chert. The following section was measured on the northern side of Shoshone Canyon:

*Section of Amsden formation on north side of Shoshone Canyon, Wyoming.*

| | Feet. |
|---|---|
| Tensleep sandstone | .. |
| Gray compact limestone | 20 |
| Dark-red sandstone, very hard | 3 |
| Light-gray limestone, very compact, containing layers of chert | 20 |
| Alternating layers of light-colored limestone and deep-red sandy shale | 20 |
| Red sandy shale containing few sandstone layers | 60 |
| Madison limestone. | |
| | 123 |

*Bighorn Mountain region.*—On the eastern side of the basin the Amsden formation is about 200 feet thick. Where the dips are steep the outcrop zone is narrow, but, in other places, as on the sloping plateaus on both sides of Horse Creek, it is broader and extends nearly to the main divide. From Cottonwood Creek northward it underlies a number of plateaus, forming wide benches on the mountain slopes, but here it is largely covered by later formations. It is deeply dissected by Devil Canyon and the valleys of Deer and Trout creeks. The lower member of the Amsden formation consists of the usual bright-red sandy shale overlying the Madison limestone, which last is often deeply stained by the red shales. In the basal shale of the Amsden there is a fine-grained, light-colored limestone about 10 feet thick, and above the shale are sandy limestones, containing in places extensive deposits of chert, which weather out and accumulate on the surface (Pl. VII, *B*). The thickness of the formation averages 200 feet, but is much less than this in some localities. At Sheil Creek Canyon the following section was measured:

*Section of Amsden formation on Shell Creek east of Shell, Wyo.*

| | Feet. |
|---|---|
| Pink sandstone overlain by flesh-colored massive sandstone of Tensleep formation | 4 |
| Light-red to maroon sandy shales | 40 |
| Gray sandy limestones, thin-bedded at top and containing much chert | 20 |
| Red shale | 75 |
| Hard, fine-grained, flesh-colored limestone | 10 |
| Red shale lying on blue-gray Madison limestone | 25 |
| | 174 |

Near the base of the formation in this locality there are some very peculiar concretions, composed of masses of silica, suggesting a coral in appearance. They vary in diameter from 6 inches to 2 feet.

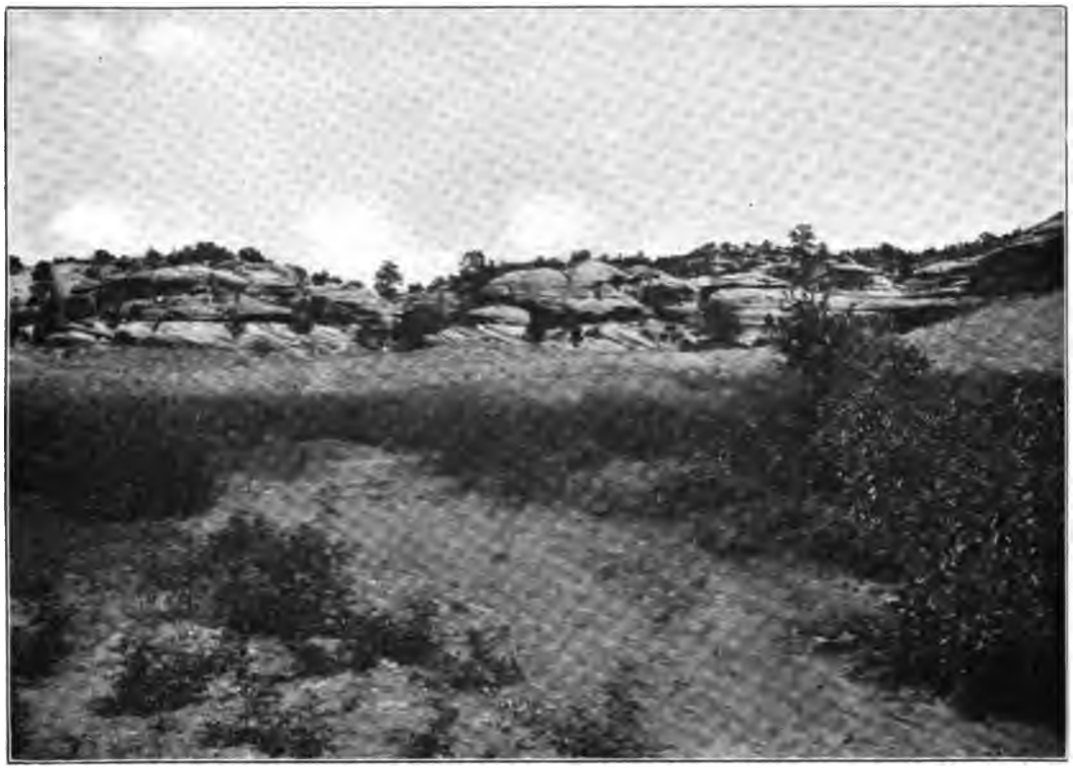
*Owl Creek Mountain region.*—The Amsden formation is exposed on the northern slopes of the Owl Creek Mountains in the southwestern part of the district, where it exhibits the usual stratigraphic sequence. The thickness here is about 200 feet and the shales at the base have the characteristic bright-red color.

### TENSLEEP SANDSTONE.

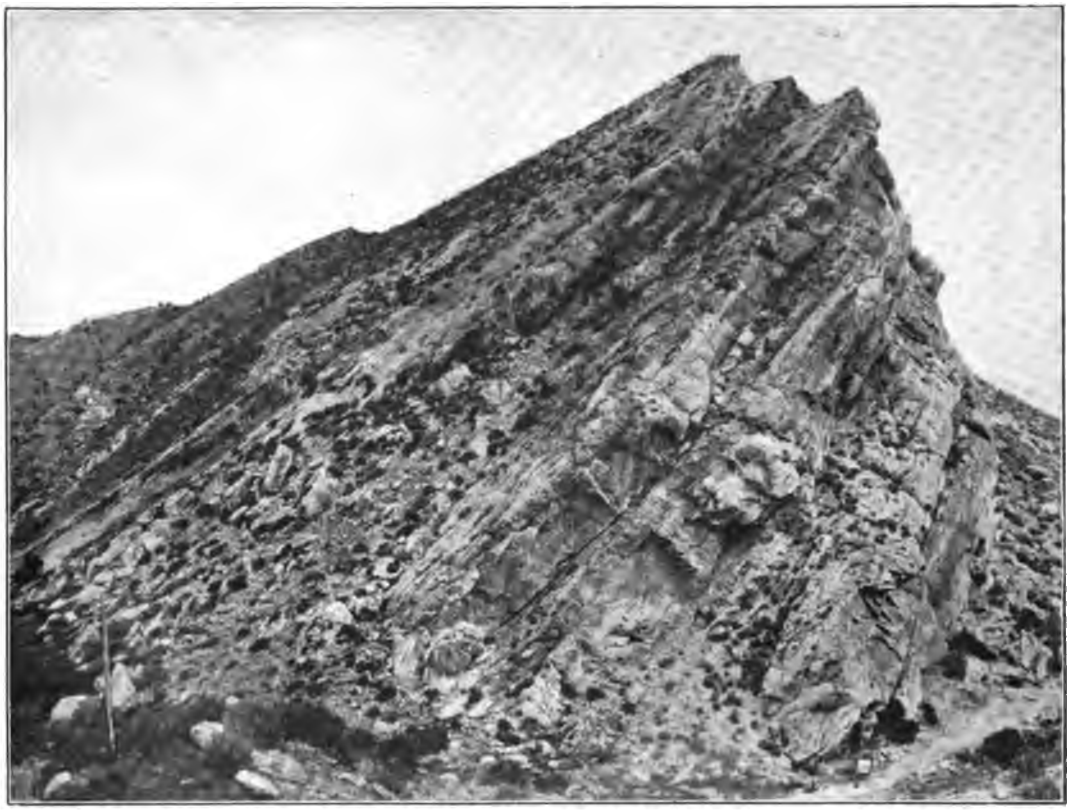
*General relations.*—The Tensleep sandstone, which overlies the Amsden formation, is prominent among the formations flanking the front range of the Bighorn, Absaroka, and Owl Creek mountains. It is also exposed in the Sheep Mountain uplift, on the eastern side of the basin, and in the high anticline southeast of Hyattville. Its thickness varies from 30 to 230 feet. The formation is composed of massive, cross-bedded sandstone alternating with beds of limestone.

*Absaroka Mountain region.*—The formation is extensively exposed on the slopes of Rattlesnake and Cedar mountains. It outcrops along the base of Black Mountain and extends far up the slopes of the inclined plateau to the north. From the vicinity of Clark Fork Canyon to the Montana line it appears in a narrow zone. In the region of Rattlesnake Mountain the sandstone is a massive, cross-bedded, light-colored rock, 150 feet thick, the upper portion of which is sometimes quartzitic. On the northern side of Shoshone Canyon, a short distance above its mouth, a section of the Tensleep sandstone, including the overlying limestones, was measured.

*Bighorn Mountain region.*—Along the base of the Bighorn Mountains, on the east side of the basin, the Tensleep sandstone usually gives rise to a ridge of moderate prominence on the lower slopes. The formation is only about 30 feet thick in the northern part of the area, but its thickness increases rapidly southward, and in Horse Creek Canyon is 150 feet. Generally the thickness varies from 100 to 125 feet. Small outliers of the formation lie high on the divide on both sides of Bear Creek; also along the road east of Cloverly, on the divide north of the mouth of Shell Creek Canyon and on the divide south of White Creek. The predominant rock is white to buff sandstone, in thick massive beds, which are cross-bedded and often weathered into very irregular forms (Pl. VIII, *A*, *B*). Where the formation



*A*



*B*

TENSLEEP SANDSTONE.

*A*. Western slope of Bighorn Mountains. *B*. No Wood Canyon, Bighorn basin, Wyoming.

is thick, the basal member usually consists of 50 feet or more of soft buff sandstone not clearly separable from the underlying Amsden formation, which usually occurs in thinner beds. The upper sandstone frequently contains a few thin limestone layers, which in other districts in the Bighorn Mountains have yielded Pennsylvanian fossils.

*Owl Creek Mountain region.*—To the southward the Tensleep sandstone is exposed only in a few small areas within the district considered in this paper. The beds in these localities exhibit no unusual features.

### EMBAR FORMATION.

*General relations.*—Overlying the Tensleep formation, on the slopes of the Owl Creek Mountains, are massive limestone and cherts, to which Mr. N. H. Darton has applied the name Embar formation, from Embar post-office, at which the beds are typically developed. The formation has a thickness of between 200 and 250 feet, and usually gives rise to long dip slopes. It is widely exposed all along the northern side of the Owl Creek Mountains, and in the vicinity of Thermopolis extends far up the slopes. Where the formation is typical, the basal member usually consists of 50 feet or more of alternating layers of light-buff limestone and sandstone. Above this there is a dark-gray fossiliferous sandstone 4 to 6 feet thick, overlain by about 90 feet of cherty limestone. Next above there is 30 to 50 feet of limestone, massive in character, capped by about 50 feet of compact sandstone, merging in color from a gray at the top to a brownish-gray or yellowish near the base. In the vicinity of Anchor the top member of the formation is 20 feet thick, resting on the massive limestone. The formation is extensively exposed throughout the Owl Creek uplift, but only a few small areas occur within the southern part of the district to which this report relates. They are found generally on anticlinal ridges branching from the main uplift. One of these occurs east of Anchor, where it is crossed by South Fork of Owl Creek, in a deep gorge, and another is southeast of Embar. The formation also appears in the more elevated portion of the anticline which passes through Thermopolis.

Large numbers of fossils occur in the Embar limestone in the walls of Bighorn Canyon south of Thermopolis. A collection was made at this locality by Mr. N. H. Darton, from which one mollusk has been identified by Dr. G. H. Girty as *Spiriferina pulchra*. This form is believed to characterize a horizon just below the so-called Permo-Carboniferous of the Wasatch Mountain region.

*Rattlesnake and Cedar mountains.*—On the flanks of Rattlesnake and Cedar mountains, immediately overlying the Tensleep sandstone, there is exposed a succession of limestone, chert, and sandstone about 80 feet thick, which is believed to be the equivalent of the Embar formation. A section of these beds on the northern side of Shoshone Canyon is as follows:

*Section of Embar formation in Shoshone Canyon, Wyoming.*

| Chugwater formation. | Feet. |
|---|---|
| Gray compact fossiliferous limestone | 15 |
| Alternating layers of cherty limestone and sandstone | 65 |
| Tensleep sandstone. | |

The top limestone of this formation contains fossils which are believed to be of Pennsylvanian age. The fossils collected from the limestone at the head of a small tributary of Sulphur Creek, on the eastern side of Cedar Mountain, have been identified by Doctor Girty as follows:

*Fossils from east side of Cedar Mountain, Wyoming.*

| | |
|---|---|
| Fenestella (?) sp. | Fragments of pelecypods. |
| Orthothetes n. sp. | Laevidentalium canna. |

From the same horizon, on the western end of a prominent red hill on the southern side of Trail Creek, the following fossils were collected:

*Fossils from Trail Creek, Wyoming.*

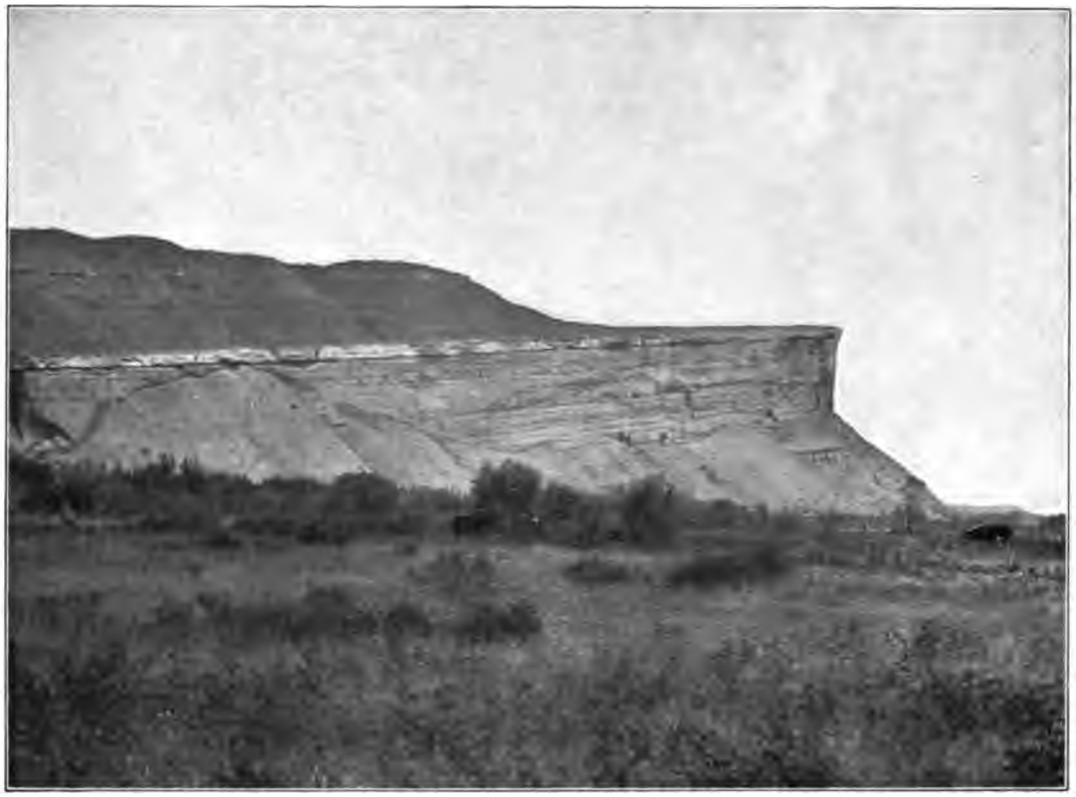
| | |
|---|---|
| Enchostoma n. sp. | Nucula (?) sp. |
| Myalina (?) sp. | Fragments of pelecypods. |
| Myalina cf. M. perattenuata. | Laevidentalium canna. |
| Leda sp. | |

## TRIASSIC SYSTEM. (?)

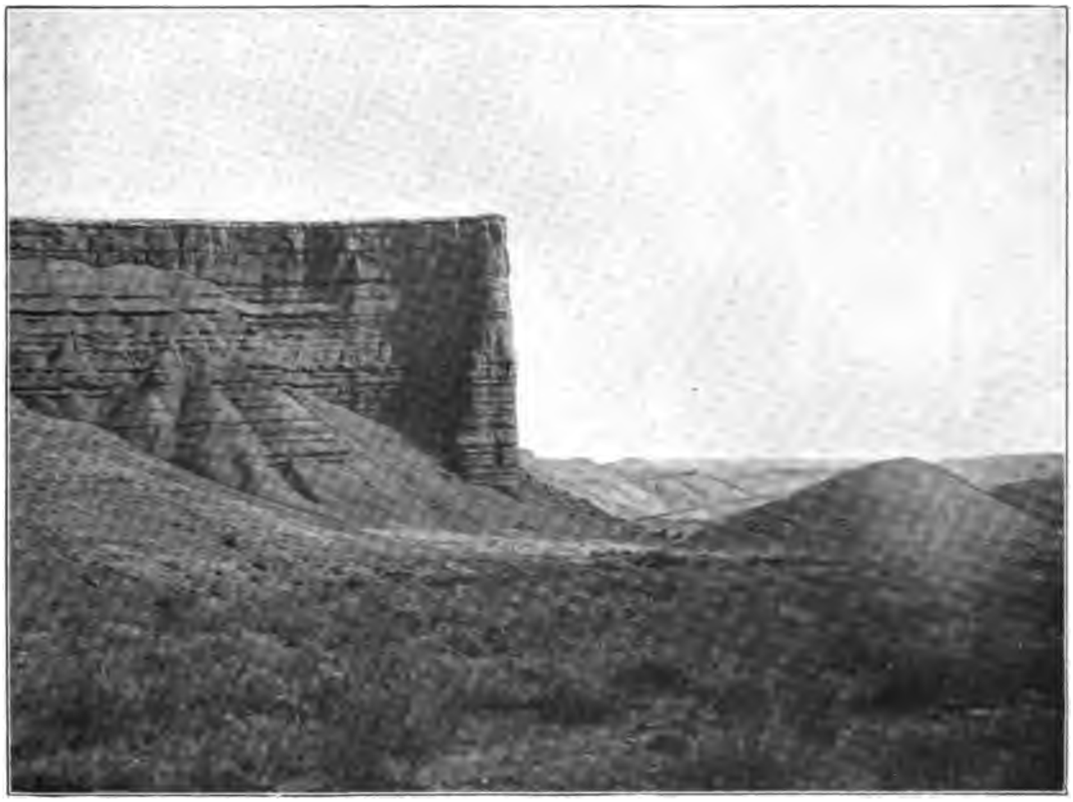
### CHUGWATER FORMATION.

*General relations.*—The Chugwater formation, which comprises the red beds of the northern Front Range of the Rocky Mountains, is extensively exposed throughout the Bighorn basin. The formation varies in thickness from 600 to 800 feet, and consists mainly of soft, massive, red sandstones with layers of gypsum and limestone. In different parts of the basin it shows considerable variation in character. Along the eastern side of the area there are generally two limestone beds, near the base, which are underlain by about 100 feet of red sandy shale, containing deposits of gypsum. The upper limestone is overlain by several hundred feet of soft red sandstone, usually outcropping in a line of prominent cliffs (Pl. IX, *A*, *B*). Above these sandstones there are about 100 feet of red sandy shale, which contains a layer of hard, thin-bedded, light-colored limestone at or near its base. Higher up are some beds of gypsum and at the top several layers of thin-bedded white limestone. Along the Absaroka front range, in the western part of the area, the formation presents a somewhat different stratigraphic succession. The basal member, about 30 feet thick, consists mainly of beds of light-gray, thin-bedded sandstone alternating with layers of limestone, the whole resting with apparent conformity on the massive limestones that comprise the upper part of the Tensleep formation. This member is overlain by 500 to 600 feet of soft, massive, red sandstones, capped by 20 to 30 feet of white gypsum. Above the gypsum there is a 12-foot layer of red sandy shale containing thin seams of gypsum which comprise the uppermost member of the formation.

*Distribution.*—The Chugwater formation occurs in extensive outcrops, especially along the eastern side of the basin. From the southern margin of the district to beyond Shell the outcrop has an average width of about 4 miles. Between Horse Creek Canyon and Cottonwood Creek, where there are steep dips, it occurs in a narrow zone along the base of the mountains. From Cottonwood Creek to the



*A*



*B*

CHUGWATER RED BEDS.

*A*. Characteristic long cliff in eastern part of Bighorn basin. *B*. Perpendicular wall near Shell, Wyo.

Montana line the dips decrease and the outcrop spreads out over a wide area, in which the formation caps several small plateaus and extends eastward far up the slopes of the mountains. The Sheep Mountain uplift exposes about 80 square miles of red beds on either side of Bighorn River from near the mouth of Shell Creek to the vicinity of Lovell. Along the western side of the basin the zone of outcrop is generally narrow, but it is present on both sides of Rattlesnake and Cedar mountains and along the base of the Absaroka and Beartooth ranges. In the southern part of the district the Chugwater red beds occupy an extensive area in the central part of the Thermopolis anticline and an area of equal size between Embar and Anchor.

*Local stratigraphy.*—Though the Chugwater formation is generally well exposed, it is often difficult to obtain a complete section at one locality. The following measurements of the lower part of the formation were obtained on Shell Creek east of Shell, Wyo.:

*Section of lower part of Chugwater formation east of Shell, Wyo.*

| | Feet. |
|---|---|
| Limestone, weathering porous, lying beneath about 600 feet of red shale and sandstone | 4 |
| Red shale | 25 |
| Thin-bedded purplish limestone | 6 |
| Red shale | 25 |
| Gypsum | 12 |
| Purplish sandy shale | 4 |
| Red shale resting on 75 feet of Tensleep sandstone | 20 |
| | 96 |

In Red Gulch, east of Cloverly, the lower members of the Chugwater formation are as follows:

*Section of lower part of Chugwater formation in Red Gulch, Wyoming.*

| | Feet. |
|---|---|
| Limestone, weathering porous, overlain by about 500 feet of red shales and sandstone | 20 |
| Green shale | 15 |
| Limestone, weathering porous | 6 |
| Green shale | 10 |
| Limestone, weathering porous | 4 |
| Red shale | 35 |
| Thin-bedded purplish limestone | 10 |
| Red shale with gypsum on Tensleep sandstone | 125 |
| | 225 |

At the mouth of Crooked Creek the lower beds of the Chugwater formation are as follows:

*Section of lower part of Chugwater formation on Crooked Creek, Wyoming.*

| | Feet. |
|---|---|
| Alternating layers of white compact limestone and gray limestone, weathering porous | 30 |
| Red and green clays | 2 |
| Alternating layers of light-gray limestone and green clay | 8 |
| Red sandy shale, green near top | 35 |
| Gray limestone | ½ |
| Gray sandstone | 1 |
| Dark-red sandy shale on Tensleep sandstone | 6 |
| | 82½ |

Near Alkali Creek, northwest of Cloverly, Wyo., a complete section of the Chugwater formation was measured:

*Section of Chugwater formation northwest of Cloverly, Wyo.*

| | Feet. |
|---|---|
| Dark-red shales overlain by gray shales containing Jurassic fossils | 60 |
| White limestone with red shale partings | 10 |
| Red shale | 20 |
| Thin-bedded, fine-grained light-colored limestone | 10 |
| Red shale | 60 |
| Red sandy shale | 50 |
| Red sandstones, some red shale | 224+ |
| Green shale | 20 |
| Massive limestone, weathering porous | 50 |
| Red shale, not well exposed | 40 |
| Thin-bedded purplish limestone | 6 |
| Red shale, not well exposed, resting on Tensleep sandstone | 80 |
| | 630 |

On the south side of Clark Fork Canyon, in the northwestern portion of the area, the formation has a thickness of about 750 feet. Here the limestone members appear to be absent, with the exception of a few thin layers at the base. The order of the beds is as follows:

*Section of Chugwater formation on the south side of Clark Fork Canyon, Wyoming.*

| | Feet. |
|---|---|
| White massive gypsum overlain by Sundance beds | 25 |
| Soft, red, massive sandstone containing layers of gypsum | 725 |
| Greenish sandy shale containing thin limestone layers on Tensleep sandstone | 10+ |
| | 760 |

About 6 miles northwest of Thermopolis, on the north side of Owl Creek, the following section of Chugwater formation was taken:

*Section of Chugwater formation near Watson's ranch on Embar road just north of Owl Creek, Wyoming.*

| | Feet. |
|---|---|
| Red beds with an occasional greenish sandy layer | 210 |
| Gray massive sandstone | 40 |
| Red beds | 20 |
| Gray massive sandstone | 10 |
| Red shale with few sandstone layers | 120 |
| Gray, thin-bedded, porous limestone intercalated with red shale | 35 |
| Alternating layers of drab fissile limestone and red thin-bedded shale | 35 |
| Deep maroon shale with spongy, angular, calcite concretions | 9 |
| | 479 |

*Age of the formation.*—The age of the Chugwater formation is not definitely known. Along the western side of the basin no fossils have been observed in the beds, and those that have been collected farther east, from the limestones in the lower part, do not furnish satisfactory evidence. The forms are not sufficiently complete or distinctive to be classed as Permian or Triassic. On Beaver Creek, northeast of Cloverly, the basal limestones contain pelecypod shells in great abundance, but they are generally too much deformed by compression to be determined. They resemble the genus *Schizodus* of the Carboniferous, one specimen being similar to *S. wheeleri* and another similar to *S. symmetricus.* The shells were diminutive, and it is possible that they are some other genus of Mesozoic age. A few fossils were obtained near Kane, but they are so small and so poorly preserved that it is not possible to determine their generic characters or relations. One shell, according to Doctor Girty, closely resembles *Myalina swallowi* of the Upper Carboniferous, but this fossil may possibly be a *Pteria* or *Bakewellia* or a Mesozoic *Mytilus* or *Modiola.* Another species suggested, by its form, *Astartella,* possibly *A. gurleyi.* All these suggestions are based on features which might also be interpreted as those of Mesozoic forms, but Doctor Girty and Mr. Schuchert are inclined to believe that they are Permian. As to the age of the overlying red sandstones of the Chugwater formation, there is no definite information; they may belong to the Permian or they may represent deposits of Triassic times.

## JURASSIC SYSTEM.

### SUNDANCE FORMATION.

*General relations.*—The marine Jurassic deposits of the Bighorn Mountains, to which the Black Hills name, Sundance, has been applied by Mr. Darton, reach a considerable thickness and carry an abundant fauna in the Bighorn basin area. The formation retains a moderately uniform thickness throughout the district, but shows variation in stratigraphy. It consists of sandstone, limestone, and shales. The shales usually predominate and have a greenish-gray color.

The formation generally outcrops in a narrow zone flanking the base of the uplifts on the eastern, western, and southern sides, but along Shell and Trapper creeks, on the eastern side of Bighorn River from Bear Creek to beyond Alkali Creek, on each side of Crooked Creek, and at the southern end of Rattlesnake Mountain, owing to low dips, the outcrop widens greatly. In the southeastern part of the district, from Hyattville to Redbanks, the zone of outcrop averages a mile in width.

*Absaroka Mountain region.*—Along the base of the Absaroka and Beartooth mountains the Sundance formation has a thickness of about 350 feet. Its base comprises a succession of light-gray to white thin-bedded limestone alternating with red and green sandy shale, having a total thickness of about 65 feet. Next above are 50 to 70 feet of dark-red sandy shale, overlain by about 150 feet of greenish fossiliferous shale containing layers of massive gray sandstone. Above this member, at the top of the formation, is a greenish, sandy shale with at least two and sometimes more layers of dark greenish-gray, fossiliferous sandstone. The following section of the Sundance formation was measured on Trail Creek, 8 miles northwest of Cody, Wyo.:

*Section of Sundance formation on Trail Creek, Wyoming.*

| Morrison shales. | Feet. | Samples. |
|---|---|---|
| Massive gray sandstone | 6 | |
| Gray sandstone, fossiliferous | 1 | 1 |
| Soft, gray sandstone | 6 | |
| Hard, gray sandstone, very fossiliferous | 1 | 2 |
| Greenish sandy shale | 30 | |
| Hard, thin-bedded, gray sandstone, containing fossils in upper part | 6 | 3 |
| Dark-gray limestone, fossiliferous | 1 | 4 |
| Greenish sandy shale; belemnites throughout | 50 | 5 |
| Greenish-gray massive sandstone | 4 | |
| Gray calcareous sandstone | 6 | 6 |
| Light-green shale, fossiliferous | 6 | 7 |
| Dark-green sandy shale | 20 | |
| Green sandy shale, containing fossils | 60 | 8 |
| Greenish gray sandy shale, capped by a layer of fossiliferous limestone | 6 | 9 |
| Red sandy shale, containing a thin band of oolitic fossiliferous limestone | 2 | 10 |
| Compact gray limestone | 1 | |
| Alternating layers of red and gray sandy shale, containing thin layers of gypsum | 50 | |
| Gypsum | 1 | |
| Gray thin-bedded limestone, weathering white | 1 | |
| Gypsum, containing layers of red shale near top | 6 | |
| Green shale, capped by a thin layer of fossiliferous limestone | 2½ | 11 |
| Gypsum | 3½ | |
| Compact gray limestone, oolitic, fossiliferous | 1½ | 12 |
| Green shale with bands of oolitic limestone | 2 | |
| Green shale | 4 | |
| Thin-bedded, gray limestone | 1 | |
| Green shale | 1 | |
| Gypsum | 4 | |
| Green sandy shale, capped by a thin layer of dark-gray limestone | 12 | |
| Gray thin-bedded limestone, fossiliferous | 3 | 13 |
| Green sandy shale with a fossiliferous limestone layer at base | 2½ | 14 |
| Green sandy shale, containing red layers | 3 | |
| Alternating layers of green shale and white gypsum | 4 | |
| Dark-green fissile shale | 5 | |
| Thin-bedded, light-colored limestone, fossiliferous | 1½ | 15 |
| Alternating layers of red and green shale | 1½ | |
| Dark rust-colored limestone, fossiliferous | | 16 |
| Alternating layers of red and green sandy shale | 1½ | |
| Gray limestone, containing fossils | | 17 |
| Green shale, containing thin layers of light-gray limestone resting on Chugwater | 3½ | |
| | 322 | |

The fossils from this locality have been examined by Mr. T. W. Stanton, and his report is here given. "The marine Jurassic fossils from Trail Creek, collected from many beds in a local section, all belong to one fauna, which is the same that occurs in Yellowstone National Park and the Black Hills." The fossils are listed below:

*Fossils from Sundance formation on Trail Creek, Wyoming.*

Lot 1. Pentacrinus asteriscus M. & H.
Ostrea.
Eumicrotis curta Hall.
Lot 2. Ostrea sp.
Pleuronya (?) sp. cf. P. subellipticus M. & H.
Belemnites densus M. & H.
Lot 3. Ostrea sp.
Belemnites densus M. & H.
Lot 4. Camptonectes.
Ostrea.
Belemnites densus M. & H.
Lot 5. Ostrea.
Camptonectes bellistriatus.
Belemnites.
Lot 6. Ostrea sp.
Eumicrotis curta Hall.
Lot 7. Belemnites densus M. & H.
Lot 8. Pentacrinus asteriscus M. & H.
Serpula sp.
Gryphæa calceola var. nebrascensis M. & H.
Lot 9. Pentacrinus asteriscus M. & H.
Ostrea strigilcula White.
Camptonectes sp.
Lyosoma powelli White
Lot 10. Oolite; no determinable fossils.
Lot 11. Nerinea sp.
Neritina (?) sp.
Two to three undetermined bivalves.
Lot 12. Modiola sp.
Cyprina (?) sp.
Lot 13. Trigonia americana Meek.
Trigonia montanaensis Meek.
Trigonia conradi M. & H.
Astarte sp.

Undetermined small bivalves.
Lot 14. Modiola sp. cf. M. pertenuis M. & H.
Lot 15. Modiola sp.
Trigonia conradi M. & H.
Trigonia elegantissima Meek.
Nucula sp.
Several undetermined bivalves.
Lot 16. Ostrea strigilcula White.
Modiola sp.
Camptonectes.
Several undetermined small bivalves.
Lot 17. Gryphæa calceola var. nebrascensis M. & H.
Trigonia elegantissima Meek. Abundant.
Astarte meeki Stanton.
Tancredia sp.
Modiola sp.

*Bighorn Mountain region.*—In the vicinity of the Bighorn and Sheep Mountain uplifts the Sundance formation is of variable constitution, changing so often that no two sections are closely alike. Soft greenish-gray sandstones predominate in its lower portion, and there is the usual thick mass of green shales above. Several hard sandstone and impure limestone layers occur at intervals, outcropping as prominent ledges, which generally are highly fossiliferous. Some typical sections follow:

*Section of Sundance formation on west side of mouth of Trapper Creek, south of Shell, Wyo.*

| | Feet. |
|---|---|
| Alternating brown sandstone and green shale | 20 |
| Dark-brown fossiliferous sandstone, hard, thin-bedded | 12 |
| Dark-green fossiliferous shale with thin-bedded sandstone at base | 115 |
| Light-green sandy shale | 50 |
| Light-colored sandy clay | 3 |
| Dark-maroon sandy clay | 2 |
| Green sandy shale with numerous small oysters | 20 |
| Gray sandstone | 1 |
| Green shale on red beds | 20 |
| | 243 |

*Section of Sundance formation on Alkali Creek, Wyoming.*

| | Feet. |
|---|---|
| Morrison. | |
| Green shale | 25 |
| Green thin-bedded sandstone | 5 |
| Brown fossiliferous sandstone | 6 |
| Green shale with belemnites and oysters | 115 |
| Thin-bedded gray limestone | 16 |
| Green shale on red beds | 75 |
| | 242 |

*Section of Sundance formation on Horse Creek, 5 miles north of Shell, Wyo.*

| | Feet. |
|---|---|
| Morrison shales. | |
| Brown sandstone, hard at base, soft at top, very fossiliferous | 25 |
| Soft greenish-brown sandstone | 25 |
| Green shale, many fossils, belemnites at base, large oysters above | 50 |
| Dark-brown and light-gray sandstones alternating, no fossils | 20 |
| Light-gray sandstone | 25 |
| Green shales, very fossiliferous | 38 |
| Brown sandstone, fossiliferous | 1½ |
| Light-brown sandstone, fossiliferous | 2 |
| Green shale, fossiliferous, on maroon shale of Chugwater | 12 |
| | 198½ |

The fossils collected at this last locality have been examined by Mr. T. W. Stanton, who reports the following forms:

*Fossils from Sundance formation, Horse Creek, Wyoming.*

Lots 1–2. Ostrea strigilecula White.
Lot 3. Dosinia jurassica Whitfield?
Lot 4. Gryphæa calceola var. nebrascensis M. & H.
Lot 5. Ostrea engelmanni Meek.
Belemnites densus M. & H.
Lots 6–7. Ostrea sp.
Eumicrotis curta Hall.

In the southern part of the district, along the base of the Owl Creek Mountains, the formation has a thickness of about 194 feet. A section taken on Owl Creek near Watson's ranch is given below:

*Section of Sundance formation near Watson's ranch on Embar road just north of Owl Creek, Wyoming.*

| | Feet. |
|---|---|
| Green sandy shale | 2 |
| Fine-grained, hard, buff limestone. This limestone breaks at right angles to the bedding plane in a singular way, so as to give the ledge the appearance of being frost-cracked or minutely spalled | 2 |
| Thin-bedded greenish-gray sandstone | 4 |
| Green sandy shale | 20 |
| Alternating layers of greenish-gray sandstone and soft greenish sands | 30 |
| Green sandy clay with many belemnites and a few oysters | 40 |
| Gray calcareous sandstone | 2 |
| Green sandy clay | 20 |
| Gray sandstone | 4 |
| Alternating layers of green, soft, sandy shales and hard, greenish fossiliferous sandstone | 70 |
| | 194 |

## CRETACEOUS SYSTEM.

### MORRISON FORMATION.

*General relations.*—The Morrison formation is extensively developed along the eastern, western, and southern sides of the Bighorn basin and shows considerable change in character throughout the area. It is composed of soft sandy shales and clays alternating with layers of massive sandstones, all of fresh-water origin. The clays have the characteristic joint-clay structure, and the sandstones are fine-grained. The prevailing color is pale green with shades of red, maroon, and purple, and in the upper part of the formation the clays are very dark. The thickness varies from 130 to 382 feet. The formation is generally exposed in a narrow band on the inner rim of a low ridge formed by the harder overlying sandstones of the Cloverly. Along the base of the Bighorn Mountains, from the Montana line southward nearly to the head of Beaver Creek, the dips are steep, and the outcrop is relatively narrow, but south of Beaver Creek, owing to decreased dips, it is much wider. Around the Sheep Mountain uplift the outcrop zone is generally narrow. Farther west, on both sides of Rattlesnake Mountain and along the front of the Absaroka and Beartooth ranges, the outcrop rarely exceeds one-fourth mile in width.

*Absaroka and Owl Creek mountain region.*—Along the western side of the basin the Morrison formation is about 150 feet thick. It consists of alternating layers of gray fine-grained sandstone and dark-gray sandy shale. Near the base there is often a thin bed of gray limestone. In one locality near the southern end of the Cedar Mountain anticline a deposit of gypsum 8 feet thick was observed near the top of the formation. Three typical sections along the western and southern sides of the Bighorn basin are as follows:

*Section of Morrison formation on Trail Creek, northwest of Cody, Wyo.*

| Cloverly formation. | Feet. |
|---|---|
| Green, sandy shales alternating with green clay containing thin layers of gray limestone throughout | 100 |
| Massive, fine-grained, gray sandstone lying on Sundance formation | 30 |
| | 130 |

*Generalized section of Morrison formation south of Clark Fork Canyon, Wyoming.*

| Cloverly formation. | Feet. |
|---|---|
| Massive greenish-gray sandstone | 80 |
| Greenish clay | 60 |
| Dark-gray limestone | 1 |
| Dark-gray sandy shale lying on Sundance formation | 20 |
| | 161 |

*Section of Morrison formation near Watson's ranch on Embar road just north of Owl Creek, Wyoming.*

| | Feet. |
|---|---|
| Massive gray sandstone | 10 |
| Concealed material, evidently soft and sandy | 125 |
| | 135 |

*Bighorn Mountain region.*—In the Bighorn Mountain region the Morrison formation consists of clay, fine sandstone, and sandy shale. The colors of the shale vary from gray and greenish-gray to maroon and purple. with some dark layers, especially toward the top. The sandstones are mostly of light-gray color and often contain large fossil saurian bones. South of Shell and southeast of Cloverly there is a massive light-colored sandstone near the base. South of Shell this bed is 20 feet thick and moderately hard, and is separated from the Sundance formation by reddish shale and overlain by massive, greenish, sandy clay. Southeast of Shell the sandstone is of light-buff color, is 40 feet thick, moderately coarse grained, and has lenses of conglomerate near the top. In places the sandstone is bright red, resembling some of the sandy members of the Cloverly formation. A typical section of the formation on Alkali Creek follows:

*Section of Morrison formation on Alkali Creek, Wyoming.*

| | Feet. |
|---|---|
| Pale-green massive shale overlain by Cloverly sandstone | 50 |
| Thin-bedded gray sandstone, brown on surface | 15 |
| Pale-green massive shale | 5 |
| Blue-black shale | 10 |
| Maroon massive shale | 10 |
| Variegated massive shale | 45 |
| Thin-bedded gray sandstone | 6 |
| Variegated massive shale, drab, purple, and maroon | 65 |
| Pale-green to white sandstone | 6 |
| Pale-green and maroon massive shale | 85 |
| Pale-green massive sandstone | 45 |
| Red sandy shale lying on Sundance formation | 40 |
| | 382 |

### CLOVERLY FORMATION.

*General relations.*—Overlying the Morrison formation in this region are sandstones for which Mr. Darton has proposed the name Cloverly formation, from the extensive exposures in the vicinity of Cloverly. The formation consists of alternating layers of sandstone and sandy clays, which are generally highly colored; buff, light green, maroon, and bright red prevail. The materials comprising the formation are very changeable. In places the sandstones are locally hard and have resisted erosion so as to stand out in typical hogback ridges; in other localities the entire succession is so soft that it weathers in low slopes and can be traced only by the bright colors which some of the members exhibit. In some localities it is possible to recognize a basal coarse-grained sandstone lying unconformably upon the Morrison shales, not unlike the Lakota sandstone of the Black Hills region, and above this a highly colored shale, overlain in turn by a massive sandstone resembling the Dakota. The basal sandstone of the succession is often very coarse-grained and pebbly and is very different in character from the underlying fine-grained sediments of the upper part of the Morrison formation. Frequently the contact between the formations is marked by an unconformity showing distinct channeling.

The sandstone of the Cloverly formation is from 10 to 50 feet thick, and the thickness of the formation varies from 100 to 300 feet. Coaly shale and coal sometimes occur associated with the basal sandstones. The area of Cloverly outcrop in the district is about equivalent to that of the underlying Morrison formation.

*Absaroka Mountain region.*—West of Rattlesnake and Cedar mountains the dips are steep and the Cloverly formation outcrops as a very narrow zone, rarely exceeding one-eighth mile in width. Along the eastern side of Rattlesnake Mountain it caps the prominent ridge between Trail and Dry creeks, and at the southern end of this ridge it extends across a saddle, through which Dry Creek passes, and joins the area exposed by the low anticline on Cottonwood Creek. Along the base of the Absaroka Range the Cloverly formation occupies a narrow but continuous zone, extending from Black Mountain to the Montana line. In the vicinity of Clark Fork Canyon its thickness is about 300 feet.

South of Cody the Cloverly formation consists of a basal coarse-grained sandstone, often pebbly, about 50 feet thick. It is overlain by softer gray sandstones of undetermined thickness. Above this occurs a layer of highly colored clay, which contains near the middle a band of dark shale. Overlying the clay is a top sandstone member, which is succeeded by the rust-colored sandstone of the base of the Colorado formation.

*Bighorn Mountain region.*—Along the base of the Bighorn and Pryor mountains and around the rim of the Sheep Mountain uplift the outcrop of the Cloverly is generally narrow, but widens somewhat on the high ridge east of Frannie, along the upper part of Alkali Creek and in the vicinity of Cloverly. South of Shell Creek the formation rises with the upward pitch of the syncline southwest of Shell and outcrops in an irregular zone extending east and west for several miles. In the anticline east of Sheldon's ranch it appears on the northern side of Shell Creek for a short distance, pitching down to the north under the basal shales of the Colorado formation. Along the foot of the mountain north of Cloverly it dips steeply for some distance, but on Alkali Creek and about Cloverly and farther south it dips very gently to the west. In the lower portion of Beaver Creek Valley the rocks are covered by alluvium, except for a small sandstone outcrop on the eastern side near the mouth of the creek. There are extensive and characteristic exposures in the vicinity of Cloverly, the type locality. Here the rocks are usually gray to buff sandstone below and massive shale or hard sandy clay above, their thickness varying from 50 to 150 feet. East and north of Cloverly the formation consists of sandstone which outcrops extensively in cliffs. It is a buff-colored rock in massive beds, mostly of moderately coarse-grained material. It is here 50 to 125 feet thick. West of Cloverly the middle and lower portions of this sandstone change to a maroon color, and some clay is intermixed with the sand.

*Section of Cloverly formation 1½ miles west of Cloverly, Wyo.*

| | Feet. |
|---|---|
| Light-buff sandstone overlain by Colorado formation | 10 |
| Tan-colored sandstone | 10 |
| Maroon clay | 4 |
| Reddish, tan-colored sandy clay | 10 |
| Drab sandy clay | 10 |
| Deep-maroon sandy clay | 20 |
| Hard, tan-colored sandstone | 3 |
| Deep-maroon to purple variegated clay | 12 |

| | Feet. |
|---|---|
| Lenses of maroon sandstone | 3 |
| Deep-maroon sandy clay | 20 |
| Olive-green, soft, cross-bedded sandstone, with hard layers lying on maroon and drab-gray Morrison shale | 10 |
| | 122 |

*Owl Creek Mountain region.*—Along the base of the Owl Creek Mountains the Cloverly formation is extensively exposed, and a small outcrop occurs at the base of the Shoshone Mountains on Gooseberry Creek near the southern end of a small anticline east of Sunshine post-office. It outcrops in a zone of varying width around the base of the larger anticline at Thermopolis and in a similar way encircles a smaller anticline lying to the east in range 93. It occupies the central portion of a small uplift which lies mainly on the east side of Bighorn River, opposite the mouth of Owl Creek, and other exposures occur along the southern margin of the district in ranges 95, 96, and 97. In ranges 98 and 99, township 43, the outcrop is narrow, owing to steep dips, and to the west, near the head of a small branch of Cottonwood Creek, it disappears under the volcanic rocks. On the western rim of the Thermopolis anticline, near Watson's ranch, the Cloverly formation has a thickness of 225 feet and exhibits the following members:

*Section of Cloverly formation near Watson's ranch on Embar road, just north of Owl Creek, Wyoming.*

| | Feet. |
|---|---|
| Gray massive sandstone of uneven hardness | 100 |
| Concealed in part, but at another exposure consists of maroon sandy shale at base, merging upward to a dull greenish gray, with an occasional harder layer of sandstone | 100 |
| Brown massive sandstone with thin-bedded layers | 25 |
| | 225 |

### COLORADO FORMATION.

*General relations.*—The Colorado formation is well developed in the Bighorn basin, being represented by beds ranging from 1,400 to 2,000 feet in thickness, but the Greenhorn limestone, which is so prominent in the vicinity of the Black Hills and along the Rocky Mountain Front Range, does not appear. The Colorado formation is exposed in a wide area in the northeastern portion of the basin, and from Shell Creek southward its outcrop varies from 4 to 6 miles in width. It is exposed in a wide area on both sides of Rattlesnake Mountain, but farther north, along the base of the Absaroka and Beartooth ranges, the beds dip steeply and the outcrop is very narrow. Small areas of the formation are exposed along the axes of anticlines east of Sage Creek, at intervals along the base of the Shoshone Mountains from Fourbear to the Antler ranch, on the divide between Rawhide Creek and Gray Bull River north of Pitchfork ranch, and on Wood River and Gooseberry Creek near Sunshine post-office. In the Owl Creek Mountain Region it occupies an area 3 to 6 miles wide, extending along the base of the mountains from a point west of Embar to the middle of range 92. South of Cottonwood Creek there is an anticline exposing 5 or 6 square miles of Colorado formation. For further details concerning the distribution of the formation see the geologic map. (Pl. III, pocket.)

*Pryor Mountain region.*—On the southern side of Pryor Mountain, 5 miles north of Cowley, the Colorado formation consists of a basal member of rusty brown sandy shales, 200 feet thick, overlain by 500 feet of very black shale, in the upper part of which occur several horizons of a light-colored clay known as bentonite. Immediately above this there are about 150 feet of hard, lighter gray shale and sandstone, constituting the Mowry beds. Next above are about 300 feet of light-gray shales alternating with sandy beds. These shales are capped by 60 feet of gray, coarse-grained, cross-bedded sandstone, often water bearing, which in turn is overlain by shales 200 feet thick, containing concretionary bands and constituting the uppermost member of the formation.

*Absaroka Mountain region.*—Along the western side of the Bighorn basin the Colorado formation is represented by about 2,000 feet of beds, of which the lower 100 feet consist of rusty brown sandstone, alternating with gray sandy shale. This basal member is usually overlain by 200 to 300 feet of very black shale, in the middle of which occurs a brown sandstone 20 to 30 feet thick. Above the shale are several hundred feet of lighter colored fissile shale, alternating with massive beds of gray sandstone that contains in its upper portion a thin deposit of coal. Above this there are 200 to 300 feet of dark shale with iron concretions, forming the uppermost member of the formation. The sandstones of the Colorado formation are sometimes coarse grained and in one locality, on Cottonwood Creek south of Heart Mountain, were observed to contain thin layers of pebbly conglomerate.

*Bighorn Mountain region.*—On the lower lands bordering the Bighorn Mountains from Shell Creek northward there is a wide area of Colorado shales in a shallow syncline or basin whose western side rises in Sheep Mountain. In the vicinity of Cloverly the Colorado shales are about 1,200 feet thick. The predominating rock is black fissile shale, with thin sandstone alternations.

The salient features of the formation west of Cloverly are as follows: At the base, lying on buff sandstone of the Cloverly formation, are about 100 feet of dark-gray to black shale, with thin brown sandstone layers, weathering to a rusty color. The shales usually begin abruptly on top of the Cloverly formation, but apparently there is no unconformity. Concretions of globular shape, averaging an inch in diameter, occur in a few feet of the lower shales, about 60 feet above the base. The concretions have a radiating structure and consist mainly of phosphate of lime, having the crystalline form of marcasite, the mineral of which the concretion originally consisted. Overlying this basal rusty succession are about 200 feet of black fissile shale, capped by 25 feet of hard sandy shale containing layers of thin-bedded dark sandstone, which represents the Mowry beds of the eastern side of the Bighorn Mountains.

These beds contain many fish scales and weather to a light-gray color. They merge upward into 30 feet of dark shale, overlain by alternating shale and sandstone, capping a high ridge. The sandstone layers are from 6 inches to 3 feet thick and are of dark-gray color. This succession may represent the upper part of the Mowry beds. At its top there is a bed of light-colored sandstone about 10 feet thick. Above this there are several hundred feet of dark-colored soft shale containing a few black concretions and in its upper portion several sandstone layers. At the top there are 100 feet of sandy buff-colored shales, with brown concretions, containing *Metoicoceras* *gibbosus*, *M. whitei* Hyatt, and *Inoceramus fragilis*. This is believed to be the top of the formation.

The calcareous shales and impure chalks which characterize the upper member of the Colorado formation elsewhere have not been distinctly recognized in the Bighorn basin. Along the base of the Bighorn Mountains light-gray shales, sometimes calcareous, lie immediately below the Pierre shale and may represent deposits of Niobrara age; but no fossils have been found in these beds. On the western side of the basin, in the vicinity of Cody, black shales, underlying the Pierre shales, contain fossils belonging to a horizon near the top of the Colorado formation. The following forms, identified by Mr. T. W. Stanton, were collected from the southern bank of Shoshone River 1 mile northeast of Cody:

*Fossils from the south bank of Shoshone River, Wyoming.*

Inoceramus acutilineata Stanton (?).
Inoceramus sp.
Crassatella.
Cardium.
Pholadomya papyracea M. & H.
Corbula.
Turritella.
Baculites asper Morton (?).
Baculites cf. B. anceps Lam.
Scaphites ventricosus M. & H.

*Sandstone dikes.*—A number of sandstone dikes cut the Colorado shales along the lowlands bordering the Bighorn Mountains. These are formed of sand that has been forced up, while wet, from underlying sandstones, through crevices in the overlying shales, probably by the pressure of a heavy load of overlying strata. These dikes vary from 6 to 10 feet in width and are composed of material similar to the Cloverly sandstone. They can sometimes be traced for a mile, generally in a direction at right angles to the trend of the mountains. A small dike of this character occurs on the divide between Bear and Alkali creeks, about 6 miles west-northwest of Cloverly, and others traverse the shales a short distance west of the northern end of Sheep Mountain.

### PIERRE SHALE.

*Character and thickness.*—In the Bighorn basin this formation is represented by lead-gray sandy shales containing occasional concretions, which are often fossiliferous. The shales are ferruginous and on weathering generally assume a yellowish color. Along the eastern side of the basin the formation is probably less than 1,000 feet thick, while at Cody and in the vicinity of Heart Mountain a thickness of 2,000 feet was measured. The shales of the Pierre formation are soft and weather uniformly, often giving rise to strike valleys between the high sandstone ridges of the underlying and overlying formations. A number of topographic depressions in the Laramie and associated formations, which are due to eroded anticlines, expose Pierre shale in their central portions.

*Distribution.*—The Pierre shale spreads out over a wide district along Sage and Dry creeks, in the neighborhood of Cowley, but to the south, on the west side of Sheep Mountain, owing to steeper dips, it outcrops as a narrow band, continuing thus to Basin. East of Basin a broad, shallow syncline, 8 to 10 miles wide, in Pierre shale, extends nearly to Bonanza, and from here to the southeast corner of the basin the outcrop zone varies in width from 2 to 4 miles. On the head of No Water and Kirby creeks the dips are low, and the formation covers a considerable area, which narrows somewhat along the northern side of the Thermopolis anticline. From Watson's ranch on Owl Creek, northwest to beyond Cottonwood Creek, a number of gentle folds in the beds occur, materially increasing the surface area of the formation. Between Cottonwood Creek and Gray Bull River a number of anticlines expose Pierre shale in their central parts, and from Sunshine post-office to Cedar Mountain it occupies an area from 4 to 10 miles wide, lying at the base of the Shoshone Range. South of Oregon basin there is an area of Pierre shale comprising several square miles, but from Wiley's ranch northward to the Montana line the outcrop zone rarely exceeds a mile in width.

### LARAMIE AND ASSOCIATED FORMATIONS.

*General statement.*—The Laramie and succeeding formations in the Bighorn basin have a thickness varying from 5,000 to 7,000 feet, consisting of sandstones, shales, and clays, with seams of coal and coaly shales. The group is extensively exposed throughout the northeastern portion of the Bighorn basin. Along the western side of Bighorn River, from Basin nearly to the head of Little Dry Creek, it is partly covered by the overlying Wasatch beds, but from the latter point northwestward to the Montana line its outcrop gradually widens. Southward from Basin the dips are moderately steep, and the formations occupy an area 3 to 5 miles wide, which continues to Bud Kimball Draw. Across the southeast corner of the basin the area expands somewhat, and to the west, across the southern side of the district, it averages about 6 miles. In the southwestern part of the basin this group is exposed over an area 10 to 12 miles wide, which in some places is covered by the Wasatch and in others sufficiently eroded to expose the underlying Pierre. In the vicinity of Sunshine post-office there is an outlier of so-called Laramie covering several square miles.

On both sides of Sage Creek east of Cody there is an extensive outcrop of Laramie, etc., due to a low, broad, anticlinal fold, which passes through Oregon basin. North of Shoshone River the outcrop occupies a relatively broad area, which is greatly contracted in its northern extension, owing to an increase in dips and a decrease in the thickness of the beds. On Line Creek the entire series apparently has a thickness of less than 1,200 feet.

*Stratigraphy.*—The sandstones of the group are generally gray, but a variable amount of iron gives rise to local coloring. Throughout the lower portion the sandstones are usually fine grained and massive and the beds are from 1 to 75 feet thick, but 25 to 30 feet is a most common measure. Where shaly intercalations predominate the sandstone generally exhibits considerable variation in character. Sandstone concretions frequently occur which vary in size from 1 to 10 feet in diameter; their form is usually elongated, with rounded edges, although spherical and lens-shaped concretions abound. In the upper part of the group the sandstones are coarse grained, containing numerous cross-bedded, pebbly, conglomerate layers, some of which attain considerable thickness. At the base of the upper half there is a conglomeratic horizon, which, owing to its increased hardness, gives rise to a hogback ridge. This ridge crosses Shoshone River near the mouth of Sage Creek. From this horizon to the base of the overlying Wasatch formation the conglomeratic layers recur in the sandstones at frequent intervals. The intercalated shales are mainly gray, but often contain a sufficient amount of carbonized wood particles to impart to the beds a lignitic character.

*Age of the formations.*—As to the age of the formations comprising this group there is some uncertainty, for no distinctive fossils were found, and the stratigraphic relations to other regions were not determined. Along the eastern side of the Bighorn Mountains the sandstone at the base of this group, which has been designated the Parkman formation, contains fossils characteristic of the Fox Hills sandstone, but in the Bighorn basin from the supposed equivalents of these beds fossils appear to be absent. Its stratigraphic position indicates that the entire succession probably represents the Fox Hills or Parkman and Laramie formations and possibly in its upper portions the Fort Union beds. The Livingston formation, which is extensively developed in Montana, may also be represented in the upper beds.

*Supposed Fox Hills sandstone.*—The Fox Hills sandstone has not been definitely recognized in the western portion of the Bighorn basin. At the base of the Laramie formation is a succession about 300 feet thick of massive gray to buff sandstone, with several layers of harder, rust-colored, concretionary sandstone. Lithologically these beds resemble the Fox Hills or Parkman sandstone on the eastern side of the Bighorn Mountains. On Polecat Creek, about 5 miles northeast of Garland, the following fossils were collected from sandstones overlying the Pierre shale:

*Fossils from Polecat Creek, Wyoming.*

Cardium speciosum M. & H.
Mactra sp., small casts.
Baculites sp., imperfect casts.
Tooth of shark.

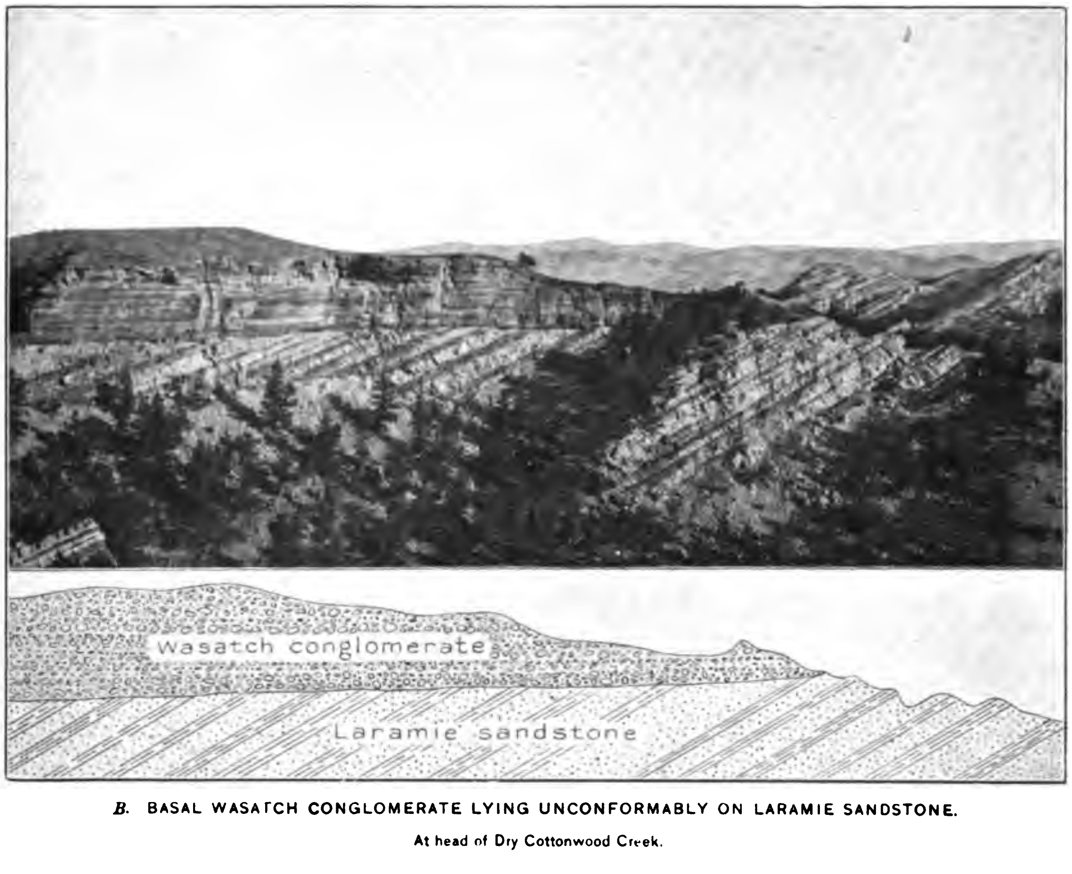
The above species have a considerable vertical range and, according to Mr. Stanton, may occur in the Judith River beds as well as in the Fox Hills. On the geologic map these sandstones are included with the overlying Laramie and associated formations.

## TERTIARY SYSTEM.

### VOLCANIC AND ASSOCIATED SEDIMENTARY ROCKS.

The Tertiary deposits of the Shoshone Mountains have not been studied in detail in connection with the present investigation. The rocks consist largely of volcanic breccias and lava flows interbedded with sandstones and shales which have a thickness of many thousand feet. They overlap unconformably all the older rocks, outcropping along the western side of the Bighorn basin, as shown in the cross sections (Pl. IV, p. 8). On the northern side of the Middle Fork of Owl Creek, near its head, fossil leaves were discovered by Mr. N. H. Darton, which have been identified by Mr. Knowlton, as follows:

*A*. SHOSHONE RIVER IN VICINITY OF CORBETT, WYO.



*B*. BASAL WASATCH CONGLOMERATE LYING UNCONFORMABLY ON LARAMIE SANDSTONE.

At head of Dry Cottonwood Creek.

*Fossils from Middle Fork of Owl Creek, Wyoming.*

Equisetum sp., one fragment.
Lygodium kaulfusii Herr (L. neuropteroides Lesq.). Abundant.
Populus cuneata Newberry. Abundant.
Populus glandulifera Herr. Abundant.
Populus zaddachi Herr. Abundant.
Quercus olafseni Herr. Two examples.
Platanus sp.? Several fragments of large leaves.
Aralia whitneyi Lesquereux. Several fragments.
Aralia notata Lesquereux. Several fragments.
Aralia, cf. A. radiata Ward. Two examples.
Sapindus obtusifolius Lesquereux. Two or three examples.
Cinchonidium, cf. C. ovata Lesquereux. Two or three examples.
Carpites sp.

From a slightly higher horizon the following forms were obtained:

Fragments of the rays of a large palm.
Ficus sp.?
Acer, cf. A. bolanderi Lesquereux. One small leaf.

### WASATCH FORMATION.

*Character and thickness.*—The Wasatch formation consists of alternating layers of sandstone and clay, with an occasional bed of conglomerate. The sandstone predominates, mostly as a soft, fine-grained, massive rock in beds which vary in thickness from 10 to 40 feet. The thicker sandstone members occur near the base of the formation, while those higher up are not only thinner, but less pure, approaching sandy clays. The prevailing color is gray, although rust-colored bands are not infrequent. The clays are sandy and contain numerous small concretions, which are sometimes fossiliferous. They are generally gray, but strata of red, maroon, and green abound, giving to the whole a banded appearance. Red colors predominate, and often serve as a means of distinguishing the formation from the underlying Cretaceous sandstone. The lower part of the Wasatch is conglomeratic, comprising 400 to 600 feet of alternating layers of conglomerate and red clay. The conglomerate is composed of pebbles derived mainly from Paleozoic sediments, with only a small percentage of pre-Cambrian material. The formation has a thickness of 1,500 to 2,500 feet and lies unconformably upon the preceding Cretaceous deposits (Pl. X, *B*).

*Distribution.*—The Wasatch has a more extensive outcrop than any other formation in the district, occupying a broad area in the central part of the basin, which narrows rapidly to the northwest. It constitutes the prominent McCulloch Peak, extends entirely around the base of Heart Mountain, occupies the low divide between Bighorn and Clark Fork basins, and gives rise to a number of prominent peaks along the base of the Beartooth Mountains from Clark Fork to the Montana line. It continues from Gray Bull south to beyond Bighorn River in the region of the Honeycombs. Along Dry Creek, Shoshone River, and Clark Fork the formation is covered by broad areas of Quaternary deposits.

The Wasatch beds contain an abundant mammalian fauna. The fossils are generally found in the clays, although their occurrence in the sandstones is not uncommon. The best collecting grounds observed were on the badlands slopes northeast of McCulloch Peak, but fossils were found all along the divide between Shoshone River and Dry Creek. These deposits have been studied jointly by Messrs. Osborn and Wortman with reference to their fossil mammalia, and they have been found to be the same as those that characterize the Wasatch formation in regions southwest of this area.

Capping some of the highest areas in the central part of the Bighorn basin, especially that part lying south of Gray Bull River, are brown, leaf-bearing, sandy shales and gray sandstones, which have a total thickness of about 600 feet. Thin coal seams sometimes occur in these beds, and in one locality on the southern side of Tatman Mountain some prospecting has been done in a seam which has a thickness of about 18 inches. A number of fossils were collected from the sandstones of this formation in the vicinity of Squaw Buttes. These have been examined by Dr. T. W. Stanton, who makes the following report:

> The small collection contains many internal casts of fresh-water fossils belonging to the genera *Unio*, *Viviparus*, and *Goniobasis*. Of the last named there are imprints of the exterior which permit identification with *G. tenera* Hall, an Eocene species. The *Unio* has about the size and proportions of *U. haydeni* Meek and the *Viviparus* resembles *V. wyomingensis* Meek, but in neither case can specific identification be positively made with such material, as there are Laramie species so closely resembling these that they could not be discriminated from the casts alone. I think that the horizon is Eocene, but I am unable to determine from these fossils whether it is Wasatch or Bridger.

These beds are extensively exhibited in Tatman Mountain and Squaw Buttes. They have been represented with the Wasatch on the geologic map.

### QUATERNARY SYSTEM.

*General statement.*—During the Quaternary period erosion preponderated throughout this general region, especially in the higher mountainous portion. Most of the products of this erosion, however, have been carried away, but some materials remain, derived chiefly from the high mountains in the western part of the area. The deposits are confined mainly to the northern part of the Bighorn basin, where they occur as extensive gravel terraces capping the high divides and bordering the larger streams. Deposits of three different periods are recognized, early and late terrace gravels and alluvium.

*Early terrace gravels.*—The early terrace deposits cap the high plateaus between the larger streams in the central portion of the basin. The most extensive of these terraces are on the high plateau northeast of Ralston, on the highland between Dry Creek and Gray Bull River, extending from the western end of Meeteetse rim nearly to Bighorn River and capping Tatman Mountain. They are composed of alternating layers of gravel, sand, and silt, having a thickness of 30 to 40 feet, and in places are underlain by light-colored sandy clays, which may be of Tertiary age.

*Later terrace gravels.*—The later terrace gravels (Pl. XVI, *A*, p. 60) border all the larger and many of the smaller streams, especially in the northern part of the district. The most extensive of these deposits lie along the northern side of Shoshone River from Garland to Eaglenest. Between Ralston and Corbett they occupy a width of about 2 miles along the western side of the river, and from there to Shoshone Canyon they occur in terraces on both sides of the river. Later terrace gravels of no great extent occur along Bighorn River and its principal tributaries to the south, No Wood and Owl creeks, and remnants of these deposits occur on Tensleep, Paintrock, and Shell creeks. Along Clark Fork and Pat O'Harra Creek there are extensive areas of the later terrace gravels. The material in the vicinity of Clark consists mainly of coarse gravel and bowlders, with a small amount of sand and silt.

*Alluvium.*—The alluvial deposits of the Bighorn basin exhibit some diversity of character, especially along the smaller streams. The alluvium along Bighorn River is of varying width, rarely exceeding 1 mile, and extends nearly across the area described in this paper. There are places throughout its course where the river flows through deep, narrow gorges in which no alluvium has been deposited. These are in Black, Sheep, and Bighorn canyons. The alluvial material is light gray, very sandy, and has a thickness of 25 to 40 feet. Shoshone River has considerable fall between Shoshone Canyon and the Garland bridge, and is in consequence a cutting rather than a depositing stream, but below this point the fall diminishes and the stream is bordered on both sides by wide alluvial flats. Here the material consists of a fine gray sand mixed with decayed vegetation and usually containing a large amount of black magnetic sand. Dry Creek Valley has a light-colored sandy wash, derived chiefly from the soft sands and clays of the Wasatch formation.

Gray Bull River and its principal tributary, Wood River, are bordered by narrow alluvial deposits, which generally contain more or less coarse material brought down by the mountain streams during the flood seasons. Below Fenton the alluvial flat widens considerably and continues thus to a point below Otto, beyond which it extends as a relatively narrow band to Bighorn River.

Most of the streams in the northwestern part of the basin, including Clark Fork, have narrow alluvial deposits. Along this river the material is coarse and contains bowlders suggestive of sediments derived from a glacier. The alluvium of the smaller streams is of local origin, and varies in character with the formations which the streams traverse. Newmeyer and Paint creek deposits contain much detritus derived from the Chugwater red beds on the higher slopes to the west. The alluvial materials on Pat O'Harra Creek, below the mouth of Skull Creek, have a dull-gray color and consist largely of wash from the Colorado and Pierre shales and from the more sandy cretaceous beds overlying them in the vicinity of Heart Mountain. On Trail Creek northwest of Cody the alluvium is composed mainly of red wash from the Chugwater formation.

The streams in the higher portion of the Bighorn Mountains flow in deep canyons or narrow valleys, where the conditions are unfavorable for the deposition of alluvium. In the lower lands farther west, which are underlain by shales and soft sandstones, wide valleys have been cut by the streams and the alluvial deposits are more extensive. The principal areas of alluvium lie along Shell Creek, occupying a belt about 1 mile wide. The deposit is from 10 to 40 feet thick. Along Beaver Creek lie narrower alluvial flats which, below the mouth of Red Gulch, attain a width of about a quarter of a mile. In its course through the red beds Trapper Creek traverses a narrow alluvial valley which joins that of Shell Creek above Shell. Along Beaver Creek and in the valley south and east of Shell the deposits contain much red detritus derived from the Chugwater red beds. In their lower courses Paintrock and Tensleep creeks have narrow alluvial valleys, which are very fertile.

Alluvial deposits of a more or less local nature occur on Dry, Dry Cottonwood, Gooseberry, Meeyero, and Owl creeks, and along the eastern side of Bighorn River on Kirby, No Water, and No Wood creeks. The alluvium of the streams draining the central portion of the basin shows some local variation, but is generally light colored and sandy, being derived chiefly from the soft sands and clays of the Wasatch and underlying Cretaceous formations. No Wood Creek in its upper course contains much red wash derived from the Chugwater red beds. through which it flows for several miles.

## STRUCTURAL GEOLOGY.

*General features.*—The mountain ranges inclosing the Bighorn basin are primarily anticlinal uplifts more or less modified by erosion. In the Absaroka, Beartooth, and Shoshone ranges the erosion has been followed by the deposition of immense sheets of volcanic breccia, which are now deeply cut by the present streams. The Bighorn basin is essentially a broad structural valley which has been formed between two large anticlinal folds, the Bighorn Mountains on the east and south and the Beartooth, Absaroka, and Shoshone mountains on the west. Across the northern end of this valley, from Heart to Pryor mountains, extends a low anticlinal fold that separates the Bighorn and Clark Fork basins, and a number of minor flexures parallel to the larger uplifts occur along the outer rim of the inclosed valley. The details of the structure of the Bighorn basin are shown in Pl. XI.

*Structure of the Bighorn uplift.*[a]—The Bighorn Mountains form a great anticline that is due to an uplift measuring many thousand feet, which begins in south-central Montana and extends southeastward and southward about 125 miles, into central Wyoming. It lifts a thick series of Paleozoic and Mesozoic formations high above the plains and, owing to the deep erosion of its crest, presents a central nucleus of pre-Cambrian granites from which sedimentary rocks dip at varying angles on each side. The most elevated portion of the uplift is in latitude 44° 30′, where one of the granite summits. Cloud Peak, has an altitude of 13,165 feet, rising about 9,000 feet above the adjoining plains. The greatest vertical displacement of the strata, as indicated by the height at which the granite floor is now found, amounts to about 18,000 feet. For the greater part of its course, the anticline is relatively simple in shape, but there are numerous local variations in the steepness of its sides and the shape of its top, owing to the presence of extensive faults. In general, its eastern side is much steeper than the western, especially in the central portion of the uplift. In its northern part both sides are relatively steep and the top is remarkably flat. In the highest portion of the uplift, which is probably near Cloud Peak, the sedimentary rocks have been removed over a considerable area, and we can only conjecture the form which the flexure would have if the eroded portions of the granite and the overlying sedimentary beds were restored. In this region there is apparently a long, uniform rise from the west, a similarly gentle grade downward to the east for some distance, and then the steep dips which are now found in the foothills on that side. The main uplift bears a number of subordinate flexures, the most notable one being east of Bald Mountain. It is an anticline rising about 2,500 feet on the northeastward dipping limb of the main anticline. A diagram of the structure of the Bighorn Mountains[b] and their southern extension, the Owl Creek Range,[c] has been published by Mr. N. H. Darton.

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[a] This description of the structure of the Bighorn uplift is taken from the Bald Mountain folio, now in press, by Mr. N. H. Darton.

[b] Geology and water resources of the Bighorn Mountains: Prof. Paper U. S. Geol. Survey No. 51.

[c] Geology of the Owl Creek Mountains, Wyoming: Senate Doc. No. 119, 59th Congress, 1st session.

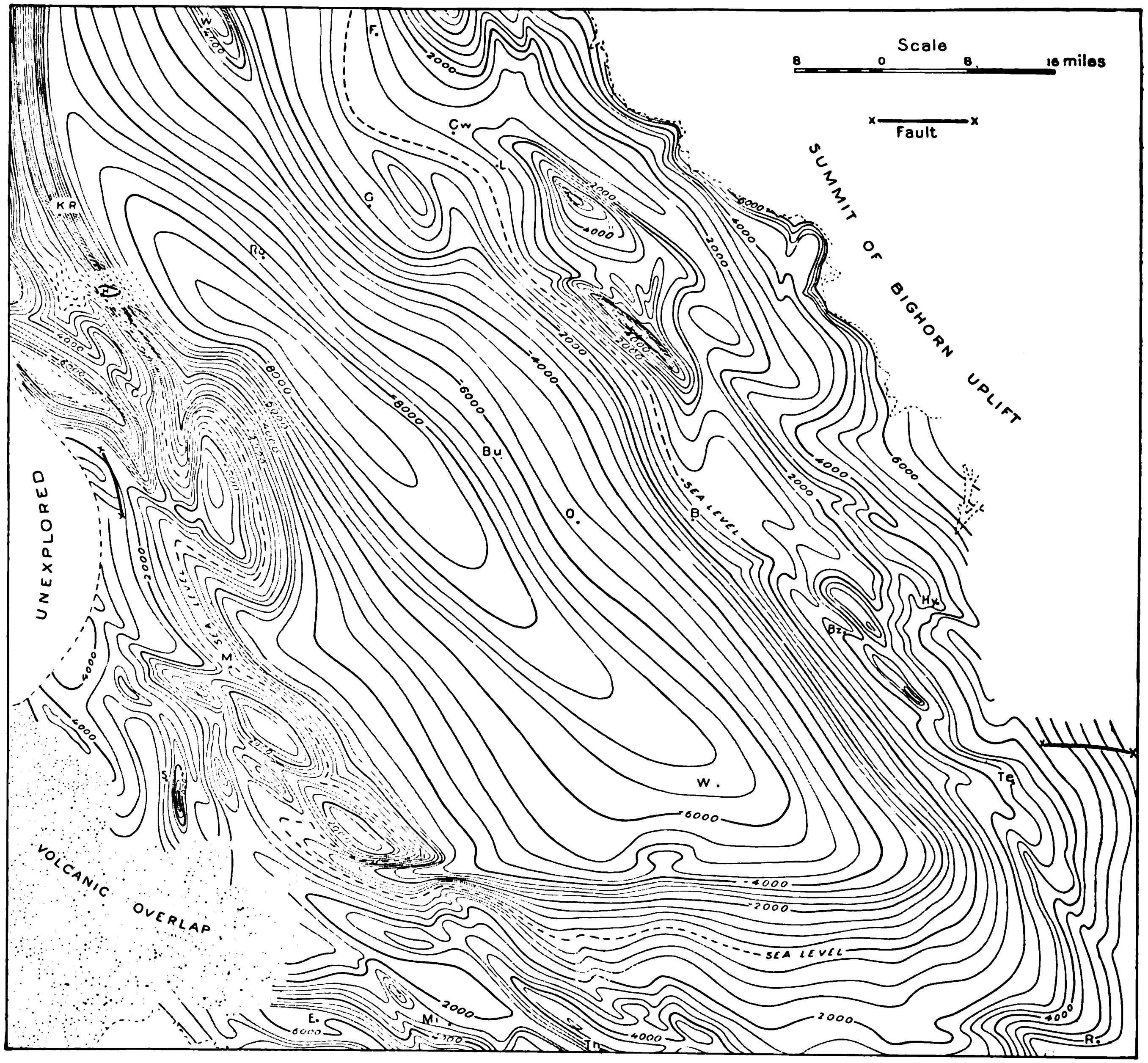


DIAGRAM OF STRUCTURE OF THE BIGHORN BASIN, WYOMING.

*Structure of the Absaroka Mountains.*—The Absaroka Mountains comprise that part of the western Rocky Mountain Front Range lying between Clark Fork and Shoshone River. This range extends in a north-south direction for a distance of about 80 miles, and has an average width of 50 miles. Only the eastern portion is included within the area to which this paper relates. The structure of the Absaroka Range is complex, but in general it is a broad anticlinal fold having a pre-Cambrian granite core, which to the east is bordered by a thick series of Paleozoic and Mesozoic formations dipping eastward with steep angles toward the Bighorn basin. These dips decrease rapidly toward the lower lands. Between Clark Fork and Shoshone River two important folds extend from the main range. The larger, comprising Rattlesnake and Cedar mountains, diverges at an angle of about 20°, and the smaller, which constitutes Black Mountain, at a somewhat greater angle.

The Rattlesnake Mountain uplift is a moderately broad anticlinal fold, with gradual slopes on the east and steep dips on the west. It lifts the Paleozoic strata about 8,000 feet above the horizon. In the deep canyon of Shoshone River the structure of the uplift is exposed down to and into the crystalline rocks. The structure of the Rattlesnake Mountain uplift is shown in the cross sections on Pl. IV, p. 8. South of Shoshone River the anticlinal bends sharply to the east, and, owing to rapidly decreasing dips, soon drops into a low arch which disappears near Frost ranch, on Sage Creek. The smaller fold projects from the main range at an angle of about 40°, and gives rise to Black Mountain. On the southern side of this mountain, at the head of Pat O'Harra Creek, the Tensleep sandstone and overlying Chugwater formation dip steeply to the southwest into a narrow syncline separating Black and Rattlesnake mountains. Across the northeast side of Black Mountain there is a bold escarpment of Carboniferous limestone overlooking the steeply dipping Tensleep and Chugwater formations. About 6 miles east of Black Mountain, along the axis of the smaller fold, stands the high, isolated peak of Heart Mountain. This mountain is capped by Madison limestone, which rises as a huge block 500 to 600 feet above the slopes of the softer Cretaceous and Tertiary formations. The limestones dip to the northeast at an angle of about 15°. The highly colored shales of the Wasatch formation surround the base of the limestone cliffs and lie unconformably upon the steeply dipping beds of the underlying Cretaceous deposits. The dip of the Wasatch beds here is somewhat obscure, but they appear to lie horizontal or possibly to be slightly inclined to the east. North and east of Heart Mountain the Wasatch beds lie against the base of the limestone cliffs. About 2 miles northwest of the peak the relation of the Wasatch shales to the underlying Cretaceous beds is well exposed. Here the latter dips at an angle of 45° to 60°, and across the upturned ends of these beds lie Wasatch shales, which dip eastward at a low angle. On the western side of Heart Mountain the dip and strike of the Cretaceous beds are unchanged from Pat O'Harra Creek to Shoshone River. The underground structural relations of Heart Mountain are somewhat obscure, but the uplift is probably due to a circular fault, which raised the Madison limestone several thousand feet above its original position. Between Heart and Rattlesnake mountains minor flexures appear, the largest exposing a small area of the Sundance formation along the western side of Cottonwood Creek. South of Shoshone River and east of Sage

Creek there is a broad anticline extending southward, in which the lowest formation exposed is the Colorado.

*Structure of the Shoshone Mountains.*—The Shoshone Mountains comprise the rugged mountainous district lying to the west of the Bighorn basin and extending from Shoshone River southward to Wind River. Carter Mountain, a prominent ridge at the northern end of the range, forms a high divide between South Fork of Shoshone and Gray Bull rivers. Only the eastern part of the Shoshone Range is included in the area described. The Shoshone Mountains were formed by an uplift which raised a thick series of Paleozoic and Mesozoic formations high above the plains, followed by deep erosion of its crest, and later deposition of a thick mass of volcanic and associated sedimentary rocks, which still retain their horizontal position. The most elevated part of the range in this district is the southern end, where a lofty peak, Washakie Needles, reaches an altitude of 12,496 feet, rising about 1,000 feet above the adjoining area.

*Structure of Sheep Mountain.*—Across the eastern part of the basin there are a number of minor flexures, of which the most prominent are those comprising the Sheep Mountain uplift. This uplift is composed mainly of two anticlinal ridges marked by Sheep Mountain along the western side in the southern part of the uplift and Little Sheep Mountain along the eastern side toward the northern end. These ridges trend N. 50° W.; they are nearly parallel, and the distance between their axes is about 5 miles. Sheep Mountain extends from near the mouth of Shell Creek to Dry Creek. It is due to a narrow anticline uplifted about 600 to 700 feet, exposing the Madison limestone along the crest of the ridge and in the walls of Black Canyon. Little Sheep Mountain begins near Shoshone River and continues southward to beyond Bighorn River, where the flexure becomes less prominent. About 2 miles east of Crystal there is an anticline exposing Chugwater beds on both sides of Alkali Creek. In its southern extension this anticline apparently joins Sheep Mountain south of Bear Creek. Farther south, along this line of uplift, there are a number of small anticlines, two near Bonanza, which expose the Sundance formation in their crest, and one on the western side of No Wood Creek below Bigtrails, which coalesces with the main uplift at its southern end. At the southeast corner of the area there is a sharp anticline through which No Wood Creek has cut a narrow, steep-sided canyon, exposing Madison limestone in its crest.

To the north, in a direct line with Little Sheep Mountain, the southern extension of the Pryor Mountain uplift occurs. The lowest beds exposed by this uplift within the area considered in this paper is the Chugwater formation. Farther out in the basin there are a few smaller folds, one east of Garland, which exposes the Pierre shale, and another east of Windsor. Northwest of Frannie there is a small anticline that exposes the sandstone of the upper Colorado formation.

*Structure of the west side of the basin.*—Extending southward from the Oregon basin there is a low, broad anticline, exposing an area of Colorado formation. Farther south this anticline coalesces with the southern extension of the Rattlesnake Mountain anticline. To the west there is a broad syncline, the western limb of which lies along Sage Creek Valley. To the north this syncline passes between the southern extension of the Rattlesnake uplift and a fault which, along its upthrow side, exposes a narrow ridge of sandstone belonging to the upper part of the Colorado formation. The position of this fault is shown on the geologic map.

To the south, in the vicinity of Meeteetse, the region is one of greater structural complexity. A series of anticlines with corresponding synclines crosses the region with a south-southeast trend from Meeteetse to the base of the Shoshone Mountains.

Beginning at the base of the Shoshone Range the first fold, which is small and unimportant in the present consideration, crosses Gray Bull River about 2 miles above the mouth of Rock Creek. This fold is exposed in the Colorado shale. To the east, along Gray Bull River for a distance of 6 to 8 miles, the surface is occupied by Pierre shale. The Laramie formation is first encountered below the Frank ranch, where a bold escarpment of sandstone faces the west. From here the Laramie, etc., extends eastward for about 3 miles in a synclinal trough, followed to the east by an eroded anticline exposing Pierre and Colorado beds. These flexures have a northern extension of 4 to 5 miles, and to the south continue to Gooseberry Creek. Still farther east, near the mouth of Rawhide Creek, there is a low syncline and anticline and to the south toward Gooseberry Creek a number of folds occur. Upper Buffalo basin, the most prominent of these, exposes a large area of Pierre in its central portions. Two small anticlines which expose Pierre shale cross Gooseberry Creek near Renner's ranch. From the eastern slope of the low anticline at the mouth of Rawhide Creek the beds extend eastward with a low, uniform dip, passing beneath the Wasatch beds toward the center of the Bighorn basin.

South of Dickie's ranch there is an anticline which presents a deep topographic depression, locally known as the "Upper Grass Creek basin." The center of this fold is occupied by Pierre shale encircled by a high wall of the overlying formation. On the south side of Grass Creek the beds dip steeply to the center of a narrow syncline in Wasatch, which extends to the west.

*Structure of the Thermopolis anticline.*—This anticline extends from the middle of R. 93, T. 43, west-northwest to the divide between Owl and Cottonwood creeks. A small area of Embar limestone is exposed on the crest of the fold near Thermopolis, surrounded by several square miles of Chugwater red beds. To the northwest the beds dip rapidly downward, carrying the Sundance, Morrison, and Cloverly formations beneath the surface a short distance beyond Owl Creek.

## HISTORICAL GEOLOGY.

*General statement.*—The geologic history of the Bighorn basin, as recorded in the various rocks outcropping around its outer portion, extends from Middle Cambrian time to the present. All the more important changes in physical geography which took place in the adjoining Bighorn and Rocky Mountain province, from the earliest Cambrian submergence to near the close of Eocene times, are recorded in the rocks of this region. These rocks comprise sedimentary strata several thousand feet in thickness which were originally a part of a much larger area now bordering the Rocky Mountain Front Range. Near the close of the epoch of early Tertiary mountain development, which resulted in the elevation of the Rocky Mountain Range and the Bighorn, Prior, and Owl Creek mountains, the district now comprising the Bighorn basin became surrounded on all sides by high mountain barriers. The elevation of these inclosing ranges probably was greater than it is at present, for subsequent erosion has removed from their summits the softer sedimentary rocks and some of the granitic nucleus.

The sedimentary rocks of the Bighorn basin consist mainly of sandstone, limestone, shale, sand, and gravel, all more or less variable in composition and appearance. The principal materials of which the sedimentary rocks are composed were originally sand, gravel, or calcareous mud derived from the decomposition of older rocks, or chemical precipitates from sea waters.

*Cambrian times.*—The lowest sediments of this period are of middle Cambrian age. They are such as characterize shore deposits along a land surface of crystalline rocks. Numerous exposures occur in which sediments containing much local material can now be seen abutting against the crystalline rocks that formed these shores. During the early part of this period the Bighorn Mountains were probably an island and the Rocky Mountain Front Range a highland rising out of the Cambrian sea. After the earliest shore-line conditions a submergence followed and finer deposits of mud were laid down, which are now represented by shales and limestones in the upper part of the Cambrian. The limestone conglomerates of the Deadwood formation indicate shallow-water conditions, and the sandstone overlying the formation probably marks the beginning of emergence which progressed through the early portion of Ordovician time.

*Ordovician period.*—Later in the early part of Ordovician time there was a submergence of this entire region, and extensive deposition of lime carbonate which at first was mixed with a large amount of silica. The shores of this Ordovician sea were probably distant, some of them being in the Laramie Range to the south.

*Silurian-Devonian times.*—Throughout the eastern portion of the district there is no geologic record from the close of Ordovician to early Carboniferous times, but to the northwest, in the Absaroka Mountains, deposits occur which are believed to represent these periods. The absence of Silurian and Devonian sediments in the Bighorn Mountains and adjoining region is difficult to account for. It may have been due to an extensive but shallow sea or land so low as to leave no noticeable evidence of erosion.

*Carboniferous conditions.*—During the subsidence which took place in early Carboniferous times, resulting in the establishment of relatively deep water and marine conditions throughout the Rocky Mountain province, calcareous sediments were laid down which are now represented by 600 to 1,000 feet of limestone, known as the Madison limestone. This formation contains no coarse sediments, a fact that suggests that possibly there were no crystalline land surfaces exposed in this region during its deposition. In regions to the south, however, limestones believed by some to be the stratigraphic equivalent of the Madison were deposited on crystalline rocks. Following the deposition of these limestones there was a change in conditions, during which beds of red shale of wide extent, followed by cherty limestone, pure limestones, and, in some places, beds of sand, were deposited, which now represent the Amsden formation. Toward the close of Carboniferous times there was an uplift, and a period of shallow water with strong currents ensued, during which time there were deposited several hundred feet of sandstone, which now constitute the Tensleep formation. At the close of this period marine conditions prevailed and limestones were deposited, followed by the deposition, in a widespread saline lake, of 700 to 800 feet of red shale containing gypsum, which now constitute the Chugwater red beds. These thick red shales and associated beds of gypsum were probably the product of an arid climate. The red color is not due to surface oxidation, but extends through the entire thickness, as has often been shown by deep borings, and is therefore the original color of the sediments. During the deposition of these red muds there were doubtless periods when, owing to evaporation, the waters became highly concentrated, and more or less gypsum was precipitated throughout the sediments, which later segregated into massive beds of gypsum as we now find them. Most of the red deposits were laid down in shallow water, so that subsidence must have kept pace with deposition while they were accumulating.

During the early part of the red-beds deposition there was an interruption which was widespread in the shale sedimentation, and a succession of relatively pure, thin-bedded limestones were laid down. In some locations outside of this area the supposed equivalents of these limestones are of Permian age, but further than this there is no satisfactory evidence as to the age of the red shales. They probably represent not only Permian, but a part of Triassic, times.

Between the red shales of the Chugwater formation and the overlying Sundance there is in this region no suggestion of an unconformity, but in most localities there is evidence of uplift and erosion of the red beds in an interval prior to the deposition of the Sundance formation.

*Jurassic sea.*—Throughout the Jurassic period shallow and deep marine waters alternated. The sediments are mainly fine grained, such as characterize waters without strong currents. Three principal events are recorded in the rocks of the formation—first, a period of shallow waters, during which sandy shales, in part ripple marked were laid down, followed by deeper water conditions, resulting in the deposition of limestones bearing an extensive marine fauna, with a return to shallow waters near the close, now indicated by sandy sediments.

*Cretaceous period.*—In the Cretaceous period deposits that vary greatly in character, but that are generally of uniform type over wide areas, accumulated. The deposits at first were such as are characteristic of shallow seas and estuaries that lie along a coastal plain, passing into sediments derived from marine waters, and toward the close changing to fresh-water materials, mainly sand and clay with marsh vegetation. The earliest Cretaceous deposits constitute the Morrison formation. This is a widespread deposit of material which is generally fine grained, consisting of clay and sand, with local beds of coarse sand deposited by streams. During this period large saurians were more or less abundant, as is indicated by the remains now found in the sandstones. The fine-grained sediments of the Morrison are succeeded by coarse, pebbly sandstones of the lower part of the Cloverly formation. Overlying the pebbly sandstones there are highly-colored, often sandy, clays, which are overlain in turn by a medium-grained sandstone, supposed to be the equivalent of the Dakota sandstone. Succeeding this period of fresh-water deposits there was submergence, and marine conditions were again established, as is indicated by the change of the sediments to dark-colored fissile shale. This marine sedimentation continued until there had been deposited several thousand feet of shale, which now represent the Colorado and Pierre formations. During this period there were several interruptions in shale sedimentation, which resulted in the deposition of sandstone and sandy shale. The most noteworthy of these was that in which the Mowry beds were laid down. During the period of Pierre deposition, which was of long duration, very uniform conditions prevailed, and there was apparently no break in shale sedimentation. The succeeding epoch marks the retreat of the Cretaceous sea. During this time there were extensive bodies of brackish water, which deposited sands, followed by fresh waters, in which were laid down several thousand feet of clay, sand, and marsh materials of the Laramie and associated formations.

*Early Tertiary deposits.*—During early Tertiary times there was extensive uplift throughout the Rocky Mountain province. This fact is indicated in the adjoining mountain districts, where late Tertiary deposits lie upon an eroded surface which has the general form of the present topography. These relations show that the uplift was truncated and the larger topographic features formed in early Eocene times. During the erosion of these uplifts there began in the Bighorn basin the accumulation of the thick sediments which now constitute the Wasatch formation. These were laid down by streams which, during most of the time, were sluggish and had extensive areas of overflow into bayous and lakes. By this means the basin was covered and partly filled with materials derived chiefly from the early Mesozoic sediments, which then extended higher on the slopes of the inclosing ranges. This derivation is shown by the character of the clays now comprising the Wasatch formation.

After a long period, during which there accumulated 2,000 to 3,000 feet of Wasatch sediments and possibly a considerable thickness of later Tertiary deposits, a new cycle of erosion began, caused either by uplift or by the development of a lower outlet for the drainage of the basin. Then began the erosion of the Tertiary deposits, but there was probably much shifting of drainage before the present system was developed.

## WATER RESOURCES.

### GROUND WATERS.

All of the larger streams in the Bighorn basin carry an abundance of good water, and in consequence few wells are needed, the water for domestic purposes being supplied by the streams directly or through the larger irrigation canals. In the vicinity of Germania a number of shallow wells obtain water from the later terrace gravels, but its quality is poor. At Garland a relatively deep surface well sunk in the Laramie formation obtained water which is highly mineralized, and there are a number of springs throughout the district which have small flows of alkali water derived from the gravel terraces.

Along Gray Bull River there are a few shallow wells that obtain water from the valley deposits, but many of the ranchers use river water. In the Bighorn River Valley the water of shallow wells is generally mineralized, and for this reason much of the domestic water supply comes from the river. The same conditions exist in the valleys of No Wood Creek and its principal tributaries. Along Owl Creek a number of shallow wells furnish water that contains more or less "alkali."

## UNDERGROUND WATERS.

A number of the formations exhibited in the Bighorn basin consist largely of porous rocks, mainly sandstone. These rocks undoubtedly contain water in their underground beds. They outcrop around the outer portion of the basin and extend far up the slopes of the ridges, where in many places they imbibe water from rain and from streams fed by melting snows on the summits of the mountains. In their underground beds they lie immediately beneath impervious shales. To this extent the conditions for underground water are favorable, but the dips are generally steep, and the water-bearing formations are carried rapidly to depths too great to be reached by practicable well borings. Along the eastern side of the basin, between the Sheep and Bighorn Mountain uplifts, there is a small area where the conditions are favorable for artesian water. The structure of the formation in this region is shown in the cross sections on Pl. IV, p. 8. In several places along the eastern side of the basin there are long monoclinal slopes of Tensleep sandstone traversed by numerous mountain streams. These slopes afford excellent catchment areas for artesian water, and at their base, in the low valleys, the conditions for artesian water are very favorable. The most promising localities are the lowlands bordering Bighorn River on the west, in the region north of Ionia, in all the larger red-beds valleys along the base of the mountains between Shell and Tensleep creeks, and in the upper parts of the valleys of Alkali, Spring, Otter, and Little Canyon creeks.

Along Owl Creek Valley, in the vicinity of Embar, and near the mouth of Mud Creek, artesian water might possibly be obtained from the Cloverly formations at moderate depth.

The water-bearing formations of the basin are the Cloverly, Tensleep, and Amsden. Of these the Tensleep and Cloverly formations are perhaps the most important. The latter consists largely of sandstone, like the water-bearing sandstone beneath the central Great Plains. Though no practical tests have been made of the water capacities of the Cloverly sandstones in this region it is probable that they contain considerable water. They lie at a depth of several thousand feet from the surface under a great part of the basin, but in the region east of the Sheep Mountain uplift, between Shell Creek and Shoshone River, they can be reached by well borings less than 1,200 feet deep. Flows could be obtained, however, only in the valleys of the streams, and as most of these streams carry an abundance of fine water artesian wells are not required. The Laramie and associated formations are water bearing, but owing to their steep dips, especially in the northern portion of the Bighorn basin, it has not been practicable to sink artesian wells into them. In Gray Bull Valley, in the vicinity of Meeteetse, however, several small flows have been obtained from the sandy members of these formations. The Tensleep and Amsden formations in the basin are very promising artesian-water horizons, but they are generally too deeply buried by overlying sediments to be reached by well borings.

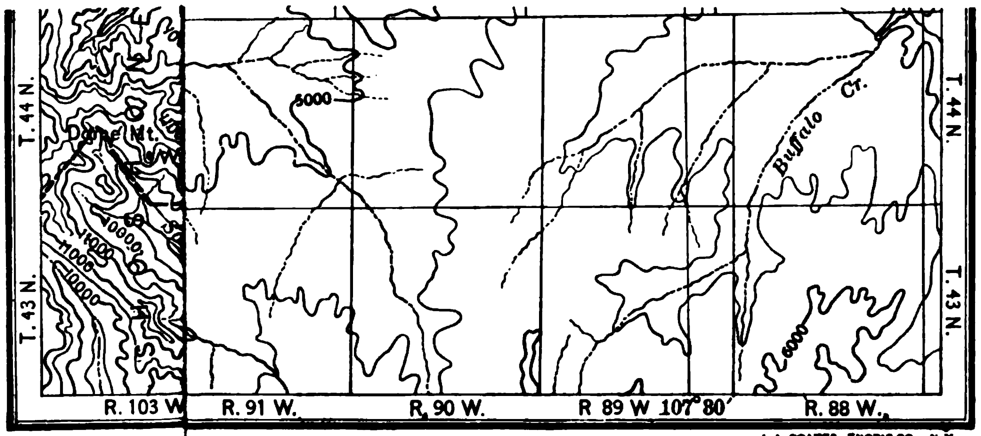
Artesian water could probably be obtained in the valley of Sage Creek, between Frannie and Shoshone River, at depths not exceeding 2,000 feet. The first water-bearing bed which would be encountered in this region in sinking a deep well is a sandstone in the upper part of the Colorado formation. At Cowley this sandstone was penetrated at a depth of about 500 feet. The next water-bearing horizon below the sandstone of the Colorado formation is the Cloverly formation, which is about 1,200 feet deeper, or approximately 1,700 feet from the surface at Cowley. Northwest of Frannie, outside the region to which this paper relates, artesian flows were obtained at a depth of 1,000 feet by the Montana and Wyoming Oil Company in borings made for oil. In the valley of Gypsum Creek there is a small area where artesian water could probably be obtained at less than 400 feet.

### IRRIGATION.

*General statement.*—Irrigation has been practiced in the Bighorn basin for about twenty years, but its growth and development have been necessarily slow until recently. The region is far from good markets, and for the first few years irrigators were compelled to depend entirely upon the local demand for the disposal of their produce. This demand has sometimes been inadequate, and farmers were obliged to hold their grain from one season to another or give it in exchange for other commodities. These conditions have retarded development in some of the irrigated districts. Settlement was first made along the eastern side of the basin, and here, in the valleys of the larger mountain streams, some of the earliest irrigation ditches were constructed. The lowlands bordering the streams were first farmed, but as the population increased higher portions of the valleys were brought under cultivation, and at present a large percentage of the irrigable lands is utilized (Pl. XII). Extensive preparations are also being made, both by the Government and by private enterprise, to reclaim large tracts of land along Bighorn and Shoshone rivers and Dry Creek in the central portion of the basin (see p. 46).

*Bighorn River.*—Along the Bighorn River Valley in the northern part of the basin irrigation is not extensively practiced. The low bottom lands are generally very sandy, and the gravel terraces bordering the river are too high to be watered by short ditches. Small marginal areas are irrigated along the western side of Bighorn River, mainly below the mouth of Gray Bull River, in the vicinity of Crystal; along Alkali Creek, a small tributary of Bighorn River from the east, and in the vicinity of Kane. None of these areas are large. The water is usually conveyed by small ditches, each ranch having a separate canal. Crooked Creek, a tributary of Bighorn River from the west, supplies water for a narrow area of valley land along both sides of the stream from its mouth to the base of Pryor Mountain. Above Basin on Bighorn River several irrigated districts occur, and at present two large canals, the Hanover canal and Bighorn County canal, are being constructed on either side of the river, which will reclaim approximately 48,000 acres of land between Winchester and the mouth of Gray Bull River.

*Shoshone River.*—At present, irrigation along Shoshone River is practiced mainly in two districts; one lying on the southern side of the river between Cody and Corbett's bridge (Pl. XIII, *A*), the other, a larger area, extending eastward from Garland bridge to Bighorn River. On the northern side of Shoshone River the Cincinnati canal covers a large area. It is about 25 miles long, and furnishes water for the region around Byron and Cowley, the total area irrigated comprising approximately 23,000 acres. South of Shoshone River is the Lovell Irrigation Company's canal, which extends from a point south of Garland to Bighorn River. This is a



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high-line canal, and when completed will furnish water for all the higher irrigable land on the southern side of Shoshone River. A number of small ditches supply water to the lower portion of the valley between Lovell and Ionia. The valley lands are very fertile, especially in the vicinity of Lovell, and a variety of crops are cultivated. Alfalfa is the staple, but during the last three years much grain has been produced. Cultivation of sugar beets has been attempted and has generally been successful.

*Clark Fork.*—Along Clark Fork and its various tributaries much land is irrigated, as shown in Pl. XII. Throughout the upper portion of Clark Fork Valley the alluvium is composed largely of coarse gravel and bowlders, containing only a small proportion of sand and silt, and in consequence is not well adapted to cultivation. The valley of Pat O'Harra Creek, the principal tributary of Clark Fork, is very narrow, but is exceptionally fertile. Along Paint, Newmeyer, and Little Rocky creeks and the upper courses of Bennett and Line creeks there are a few small irrigated farms.

*Gray Bull River.*—Irrigation is extensively practiced along the entire course of Gray Bull River, but the amount of water in the stream is not adequate for the irrigation of all the valley lands without storage of its flood waters. A preliminary survey was made in 1899 for the purpose of locating a storage reservoir on the headwaters of the Gray Bull, and, as a result of this investigation, a dam and reservoir site was located on the river about 10 miles above Fourbear. The approximate boundaries of the irrigable lands are shown in Pl. XII. The soil is very fertile, and a large amount of hay and grain is raised in the vicinity of Meeteetse, where irrigation has been practiced for many years (see Pl. I, *B*).

*Shell Creek.*—The waters of Shell Creek and its tributaries have been used for irrigation for nearly twenty years. The stream has a large flow of water, and its fall is about 25 feet to the mile. It is bordered by a relatively wide valley, which has gentle slopes, affording ideal conditions for irrigation. The soil is generally deep and fertile and well adapted to the cultivation of a variety of crops. A number of small ditches have been taken out on both sides of the stream, and a large part of the land is farmed. Alfalfa is the principal crop, but grain also is raised. There are a number of bearing orchards along Horse Creek, the largest tributary of Shell Creek from the north. The seasons are of sufficient length in this region to insure the maturity of most crops.

*Other flowing streams.*—A portion of the land is irrigated along the valleys of Gooseberry, Grass, and Owl creeks. The latter has a wide, fertile valley, only a part of which is irrigated, owing to a shortage of water. Owl Creek has a vigorous flow for a short period during the flood season, but this flow rapidly decreases, and in midsummer the stream below Embar is nearly dry.

On No Wood Creek and its principal tributaries, Paintrock and Tensleep, the valley land is extensively irrigated. The soil along these streams, although predominately sandy, is very fertile, and a variety of crops are cultivated. Small storage reservoirs have been located on Dry Cottonwood and the East Fork of No Water creeks, and the land to be irrigated from these reservoirs is shown in Pl. XII.

*Dry Creek.*—Around Germania there is an irrigated district comprising about 12,000 acres, which receives its water supply from the Branch canal. This canal is diverted from Gray Bull River in the vicinity of Fenton. A large acreage of oats, wheat, and alfalfa is here under cultivation; also a variety of vegetables. As Dry Creek is an intermittent stream the community is dependent upon the ditch water for domestic uses as well as for irrigation.

The Bighorn Basin Development Company is now making preparations to reclaim all the irrigable lands along Dry Creek from Oregon basin to Bighorn River. The water is to be taken from South Fork of Shoshone River near the mouth of Belknap Creek and carried through a high-line canal for nearly 30 miles to Oregon basin, where it is to be stored. From here it will be distributed by two large canals—the Shoshone and the South Fork. The lands to be reclaimed by this company are shown in Pl. XII.

*Irma Flats.*—Southwest of Cody, Wyo., is a small farming district comprising about 2,000 acres, known as the Irma Flats. This district is supplied with water by the Cody canal, which has its headgate on South Fork of Shoshone River near the mouth of Marquette Creek.

*Shoshone project.*—The Government is now constructing a dam across Shoshone River at the upper end of Shoshone Canyon for the purpose of storing a portion of the flood waters of that river. The dam is to be 85 feet wide in the river bed and 165 feet wide at an elevation of 210 feet. A dam of this size will have a storage capacity of 159,500 acre-feet. The water from the storage reservoir is to be used for irrigating along the northern side of Shoshone River in a district extending from the mouth of Shoshone Canyon to beyond Frannie station, a distance of about 60 miles, and comprising an area of about 282,000 acres of level land. (See Pl. X, *A*.) The distribution of the land to be irrigated is shown in Pl. XII, and the proposed dam site (Pl. II, *B*) and storage-reservoir site in Pl. XIII, *B*.

## MINERAL RESOURCES.

### COAL.

#### GENERAL DESCRIPTION.

Coal is the principal mineral resource in the sedimentary formations of the Bighorn basin. It occurs mainly in the so-called Laramie formation, although on the western side of the district a coal, said to be of good quality, is found in the upper part of the Benton group, and on No Wood Creek, 12 miles southeast of Bonanza, a local deposit of coal is mined from the Cloverly formation. The coal is found at various horizons throughout the Laramie and associated formations, but most of the deposits of workable thickness are in a basal member of this formation or possibly in beds still lower. Coal is widespread in its distribution within the area occupied by the Laramie and associated formations. The greatest development, however, is found in places where the larger streams expose the coal measures. Here the most favorable conditions exist for locating mines and the increased settlement of the irrigated valleys along the streams afford local market for the coal. The various districts in the Bighorn basin, where the principal development of the

*A.* SHOSHONE RIVER VALLEY NEAR CORBETT, WYO.

*B.* SHOSHONE RESERVOIR SITE.

North and south forks of Shoshone River above Shoshone Canyon.

coal deposits has taken place, are described separately. The limits of these districts are arbitrarily taken and they are designated by the nearest town.

### CODY DISTRICT.

Coal is mined at several localities in the vicinity of Cody. The Navine mine, 3½ miles northeast of Cody, on the opposite side of Shoshone River, is the oldest mine in the district. Coal has been taken out of this opening for several years to supply a small ranch trade along the valley. The deposit is between 2 and 3 feet thick. During the last three years the increase in population in the vicinity of Cody has caused a greater demand for fuel, and in consequence several new mines have been opened. These are the Burns & Rogers mine, the mine of the Cody Coal Company, and others. The Burns & Rogers mine is situated 5 miles south-southeast of Cody, on the west rim of a small syncline through which Sage Creek flows. The coal here is in the lower portion of the coal-bearing measures. The deposit consists of three benches separated by two slate partings. It has an eastward dip of 47° and is included in beds of massive gray sandstone. An incline 90 feet deep has been driven on the seam, with a large room on either side. The coal is hard and black, with a bright luster and uneven fracture. It does not break up badly on exposure to atmospheric agencies and as a domestic coal is said to be very satisfactory. The product of this mine will probably never be large, for the deposit is thin and the dip of the beds is so steep that the limit of economic working will soon be reached. This coal finds a market in Cody and in the Shoshone River Valley. The following section was measured at the Burns & Rogers mine:

*Section at the Burns & Rogers mine, near Cody, Wyo.*

| | Ft. | In. |
|---|---|---|
| Coal | | 10 |
| Impure coal | | 6 |
| Coal | 1 | 2 |
| Gray slate | | 3 |
| Coal | 1 | |

During the past season the Cody Coal Company has opened a mine on the northern side of Shoshone River about 3 miles east of Cody station. The coal occurs about 1,500 feet above the top of the Pierre shale in beds dipping at an angle of 45° to the east. The deposit is about 4½ feet thick and is apparently of good quality, although no analysis of the product was available. The opening of this bed is in the face of the bluffs about 30 feet above the railroad, so that the coal can be loaded for shipment at small expense when the new side track now being built is completed. The mine is well timbered and preparations are being made for more extensive development. A section of the deposit is as follows:

*Section of Cody Coal Company's mine, Cody, Wyo.*

| | Feet. |
|---|---|
| Dark sandy clay | 6 |
| Coal | 4 |
| Coaly shale | 2 |
| Dark sandy clay | 8 |
| Gray massive sandstone | 20 |

Arrangements are now being made by another company to develop coal beds at the same horizon on the southern side of Shoshone River.

Some prospecting has been done on Sage Creek and its tributaries in the vicinity of Frost's ranch. Other prospects occur in the high bluffs of Wiley's ranch and on Dry Creek east of Oregon basin. None of these openings are worked at present. Some development work has been done on a bed of coaly shale on the eastern side of Sage Creek about 2 miles above its mouth. The coal occurring in the Colorado formation just west of Cody bridge was formerly mined to some extent.

### MEETEETSE DISTRICT.

In the vicinity of Meeteetse there are a number of coal mines which have been operated more or less extensively for the last fifteen years. The region is one of considerable structural complexity, with a number of low anticlines and intervening synclines crossing it. This folding has greatly increased the surface area of the coal-bearing formations, bringing the productive beds near the surface over a considerable area.

The Conie mine, on the Meeteetse rim, 12 miles northwest of Meeteetse, was reopened in 1903 after lying idle for several years. The coal is in relatively thin beds, lying nearly horizontal. It is black with an unusually bright luster, brown streak, and subconchoidal fracture. The woody structure is maintained to a marked degree, and its resistance to weathering is slight. Its occurrence in a soft-clay formation renders it difficult to mine and the absence of a solid roof necessitates elaborate timbering, greatly increasing the cost of operation. The mine is located in an inaccessible place and will probably never be extensively developed. The character of this coal bed is illustrated in the following section:

*Section at Conie mine, near Meeteetse, Wyo.*

| | Ft. | in. |
|---|---|---|
| Coal | 1 | 2 |
| Bony coal | | 7 |
| Coal | | 11 |
| Dark-gray slate | | 4 |
| Coal | 1 | 6 |
| Dark-gray slate | 1 | 8 |
| Coal | 1 | 6 |
| Slate | | 4 |
| Coal | | 8 |

The Orr mine is situated on a branch of Meeteetse Creek, about 3 miles northwest of Wise. It is well opened with a double well-timbered entry, extending 100 feet from the outcrop. The bed consists of two benches, each 3 feet thick, separated by a layer of light-bluish-gray slate which is characteristic of this horizon. The coal is black with a bright luster, brown streak, and uneven fracture. This mine is worked during the winter months with a seasonal output of 300 to 400 tons. Considerable prospecting has been done near the Orr mine and one opening has been made about a mile south which exposes a 6-foot bed of coal.

The Blake mine is located about 3 miles above Meeteetse, on the north bank of Gray Bull River. Here a seam 5 feet 9 inches thick has been extensively operated, and is one of the oldest openings in the district. The dip of the beds is 9° NE. The main entry is about 150 feet in length, with several side entries. The workings are too low in the river bank for perfect drainage to be effected, and some little difficulty has resulted from this condition. Operations were first begun at this place in 1892, but there was only a small output until 1898, when the property was purchased by the present owners. The total production from 1898 to 1902 exceeded 2,000 tons. In 1902 the product amounted to 900 tons with a market value of $2 per ton at the mine. At present the mine is not worked. There is another opening on the same horizon a short distance up the river which was formerly owned by McDonald & Cottle, of Thermopolis. The dip in this region is low and the conditions are generally favorable for more extensive development of these properties.

*Section at the Blake mine, near Meeteetse, Wyo.*

| | Ft. | In. |
|---|---|---|
| Bony coal | | 6 |
| Clay and sandstone | 6 | |
| Coal | 3 | 3 |
| Bluish-gray slate | | 3 |
| Coal | 2 | 6 |
| Impure coal | | 6 |

During the summer of 1904 an opening was made on a bed of coal in the upper part of the coal-bearing formations near the mouth of Meeteetse Creek, about 2 miles north of Meeteetse, Wyo. It is now known as the Woodruff mine. The seam is 4 feet thick with no partings. It is overlain by hard, gray sandstone and underlain by a dark-colored compact clay. An entry 150 feet deep has been driven in the seam, with several large rooms on either side. The coal is hard and black with a bright luster. It appears not to break up badly upon exposure, and as a domestic coal is said to be very satisfactory. No analysis has been made of this coal. During the past two years the Woodruff mine has had a total output of 2,200 tons, which sells at $2.25 per ton. The coal finds a ready market at Meeteetse, Wyo.

Another mine recently opened near Meeteetse is owned by Mr. Erskin. It is located in sec. 13, T. 48, R. 101, about 2½ miles above Meeteetse, in the lowland of the Gray Bull Valley. This mine is on the same seam as the Edward Blake mine, which has been worked for many years on the northern side of Gray Bull River. The coal beds have a dip of 6° to the east and are somewhat thicker than on the opposite side of the valley. The output for last season, during the period of development of the mine, was about 400 tons.

There is a bed of coal 3 to 4 feet in width, occurring in dark-gray sandy shales 400 feet below the base of the Wasatch, about 3 miles southeast of Meeteetse. This coal has been prospected at a few places along the stage road between Meeteetse and Moon's ranch, on Gooseberry Creek, but no mines have been opened. It is possible that a more extended search for coal at this horizon might result in the discovery of workable beds.

That portion of the Meeteetse district lying south of Gray Bull River is separated into two parts by erosion along an anticlinal fold. The main body of coal-bearing measures lies east of Wood River, between Gray Bull River and Gooseberry

Creek, and a detached portion occurs west of Wood River. There are several anticlinal folds in the main body which bring the lower coal-bearing measures of the Laramie to the surface in a number of places along Gooseberry Creek, but openings have been made in only two localities. In a small ravine entering Gooseberry Creek from the south, and on the eastern rim of a small anticline, there is a coal opening known as the Dickie mine No. 1. This mine exposes a bed of bright, clean-looking coal 4½ feet thick without parting. The coal is immediately overlain by a 2-foot layer of gray clay, fine grained and compact, containing carbonized plant fragments. The coal is in the lower part of the coal-bearing measures and dips at an angle of 17° ENE. The mine has never been worked extensively and the main entry extends but a few feet. The coal, however, is of good quality and the general conditions are favorable for development. There is another bed about 12 feet lower, the general character of which could not be ascertained owing to talus. The accompanying section shows the relative position of the two beds:

*Section at the Dickie mine No. 1, on Gooseberry Creek, Wyoming.*

| | Feet. |
|---|---|
| Gray compact clay | 2 |
| Coal | 4½ |
| Gray clay | 3 |
| Buff sandstone | 6 |
| Brown sandstone | 2 |
| Impure coal | 6 |

About 3 miles southeast of Dickie mine No. 1, and 1 mile north of Grass Creek, Mr. Dickie has opened a coal bed 8 feet 3 inches thick, which is locally known as Dickie mine No. 2. The coal occurs near the base of the coal-bearing measures, which here comprises the western rim of a large eroded anticline extending from the vicinity of Gooseberry Creek southeastward to Grass Creek and intersecting the latter at a point 3 miles above the mouth of Prospect Creek. The longitudinal axis of this anticline is 12 to 15 miles long and the transverse axis is considerably shorter. The central body of the basin is composed of Pierre shale, surrounded by coal-bearing sandstone. The only coal openings observed on this sandstone rim were the Dickie mine No. 2 and a small showing on the southern side of Grass Creek about a mile distant. Coal of this horizon is said to outcrop, however, at frequent intervals along the southern rim of the anticline for some distance. The coal seam in Dickie mine No. 2 consists of two benches, separated by the usual bluish-white shaly parting near the middle. A 2-inch layer of light-gray shale also occurs near the top of the upper bench, but neither of these partings is sufficiently thick to affect materially the productive capacity of the seam. The coals of the upper and lower benches exhibit no essential points of difference in quality. The product is rather hard and compact, with an unusually bright luster, and a chemical analysis shows it to be an average quality of lignite. The mine is not operated at present, but the quality of the material, combined with the size and character of the seam, render it a desirable property. A section of the bed is given below:

*Section at Dickie mine, No. 2, near Grass Creek, Wyoming.*

| | Ft. | in. |
|---|---|---|
| Coal | 4 | 6 |
| Light bluish-gray slate | | 3 |
| Coal | | 9 |
| Light-gray slate | | 2 |
| Coal | 3 | |

The small detached area of coal-bearing measures lying west of Wood River is structurally a synclinal trough comprising about 25 square miles and extending from a point 3 miles north of Gray Bull River southeastward to Wood River. This area is about 10 miles long and 2 to 3 miles wide, and its axis trends N. 5° W. The formation is the lower part of the coal-bearing measures. The sandstones of this formation in the region are heavily developed, and massive sandstone layers 20 to 30 feet thick occur immediately above and below the coal horizon, the upper having a white and the lower a yellowish tint. The color and thickness of these two sandstone layers are very persistent throughout the Meeteetse district, and serve as an indicator of the position of the coal. The dips vary from 20° to 40° from rim to center, with a direction according to their position on the periphery of the syncline. They are very steep along the eastern and northern sides, but to the west and south they decrease materially. The area is encircled by a continuous coal outcrop. The lower coal bed of the basal sandy division probably underlies the entire district, and the upper seam, 75 feet higher, here locally attains a workable thickness. Development has been chiefly confined to Sunshine Gulch and its tributaries, about 3 miles north-northwest of Sunshine post-office, although openings have been made at other points within the area. None of these localities are operated at present, but the coal is said to be of good quality. The average thickness of the lower coal bed in Sunshine Gulch is 6 feet, while the upper seam is only 2 feet 8 inches.

A coal bed averaging 3 feet in thickness contains about 3,000,000 tons of coal per square mile, but of course there is considerable loss in working. There are now in this field about 18 square miles underlain by coal that would doubtless average 4 or more feet in thickness. On this estimate the field has a productive capacity of 72,000,000 tons. A trial pit near the north end of this area, in the sandstone bluffs on the south side of Gray Bull River, exhibits the following section:

*Section at Vetter's coal opening, near Meeteetse, Wyo.*

| | Ft. | in. |
|---|---|---|
| Bony coal | | 3 |
| Coal | | 10 |
| Bony coal | | 2 |
| Coal | 1 | 8 |
| Light bluish-gray slate | | 3 |
| Coal | 1 | |
| Dull-gray slate | 1 | |
| Coal | | 4 |
| Bluish-gray clay | 2 | 6 |

South of the Meeteetse district, in the vicinity of Embar, there is a small opening known as the Smith mine, which was formerly operated to some extent, but at present is abandoned. Some of the earlier analyses of this coal show a high fuel ratio, but an unusually large amount of moisture. There is another small mine, about 2½ miles northeast of Middleton post-office, known as the Eades mine. The bed is 4 feet thick without parting, and occurs in the massive gray sandstone not far above the top of the Pierre shales. The beds dip 9° to the north. From an incline about 60 feet in length that has been driven on the dip a small amount of coal is taken out during the winter season. The coal in appearance is black, with a bright luster and uneven fracture. It does not weather easily. The following section was measured:

*Section at Eades mine, near Middleton, Wyo.*

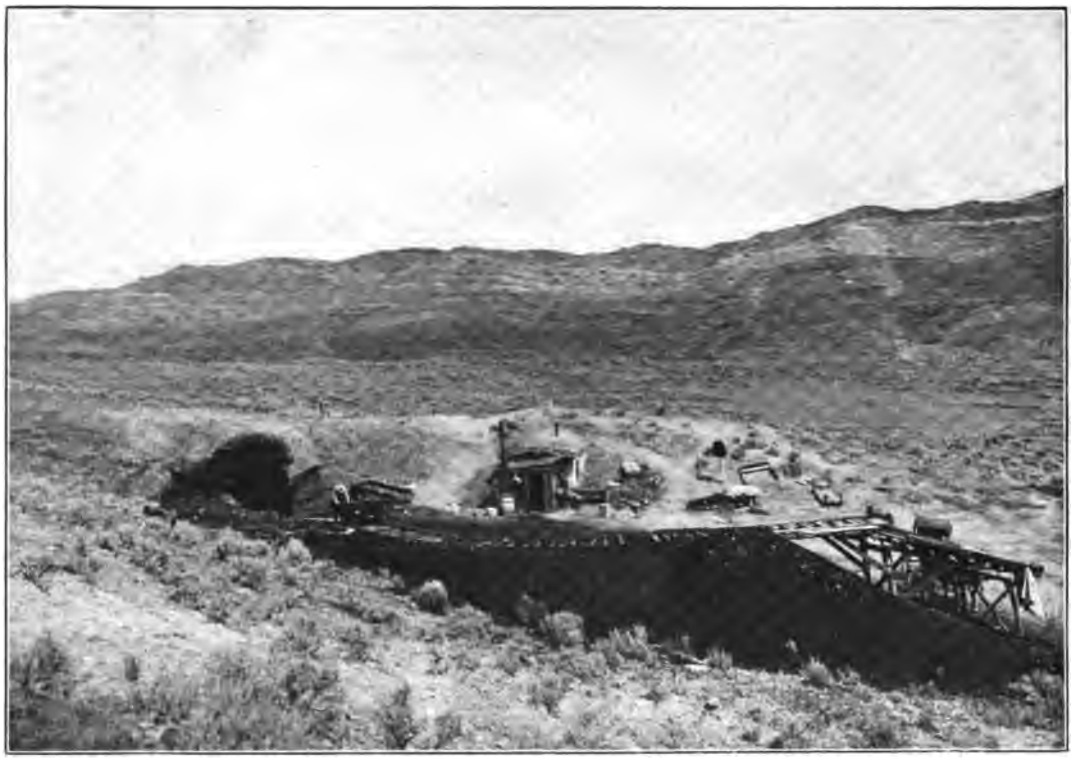
| | Feet. |
|---|---|
| Dark-gray compact clay | 2 |
| Impure coaly shale | 1 |
| Coal | 4 |

### THERMOPOLIS DISTRICT.

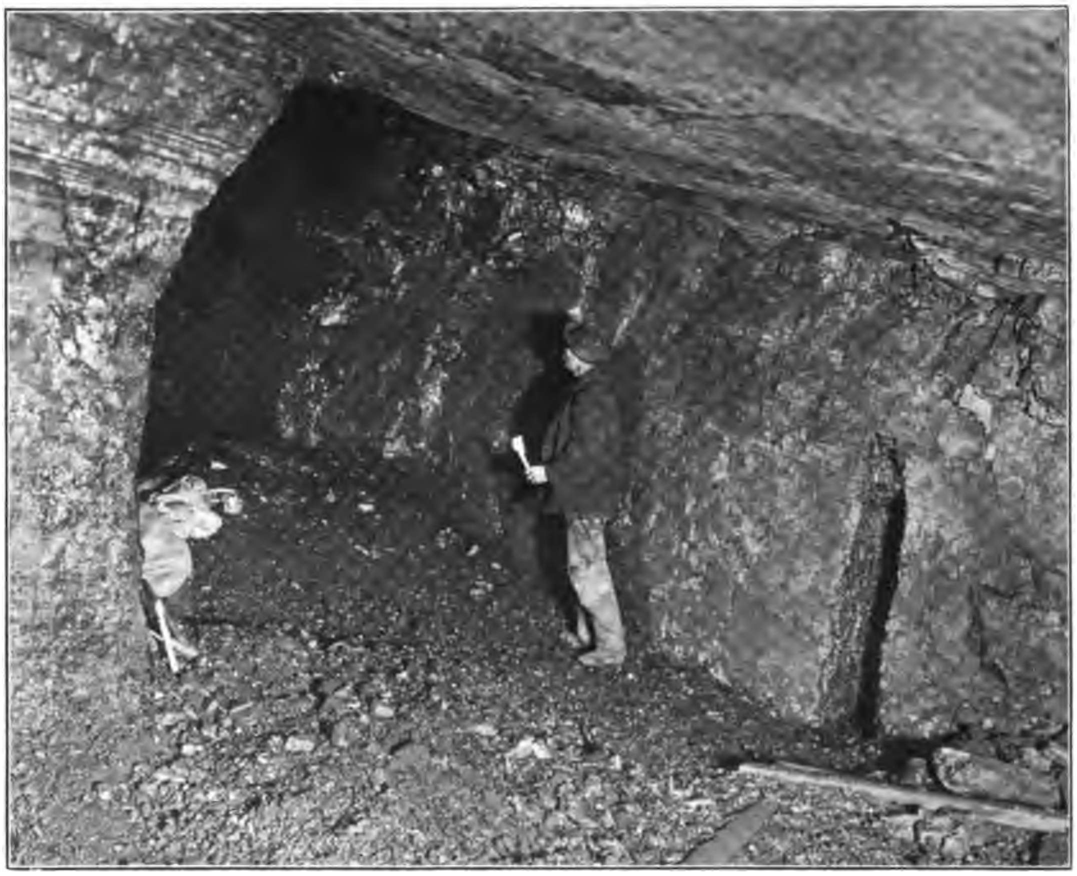
This district is located on the western side of Bighorn River, about 12 miles north-northeast of Thermopolis, and a few miles below the mouth of Kirby Creek. The formation consists of alternating layers of massive gray sandstone, sandy shale, and clays with a locally developed clinker bed occurring immediately below the principal coal seam of the district. This is the only clinker bed thus far observed in the Bighorn basin. The dip of the beds is 17° NNE. The Jones mine was opened in this district in the summer of 1889, but the output was small for the three following years, scarcely exceeding 200 tons a year. Since 1900 the annual output has increased to over 1,000 tons, but as yet only a small part of the field has been worked, and the present production of this locality could be increased many times. Operations have now ceased at the Jones mine, and a new opening has been made by McDonald & Cottle (Pl. XIV, *A*). The principal bed is 9 feet thick, overlain by a bed of sandy clay of variable thickness. Above this is another coal bed 5 feet thick. In the McDonald & Cottle mine the sandy clay reaches a minimum thickness of 2 inches, which practically unites the two seams, giving a total thickness of 14 feet (Pl. XIV, *B*). This is the thickest coal seam thus far observed in the Bighorn basin. Five other closely adjacent beds occur, four below and one above the 14-foot bed; three of the lower beds are said to be workable. The uppermost, outcropping 25 feet below the McDonald & Cottle vein, is 3 feet thick and apparently of good quality. The total thickness of the various beds exposed within close vertical range is approximately 30 feet. The material is a bright, firm, free-burning variety of coal. It gives a brown streak, breaks in blocks, and does not crumble easily on exposure. An analysis shows a rather high per cent of fixed carbon and moisture and only a small amount of ash. At the McDonald & Cottle mine the following section was taken:

*Section at the McDonald & Cottle mine, near Thermopolis, Wyo.*

| | Ft. | in. |
|---|---|---|
| Coal | 5 | |
| Dark-gray sandy clay | | 2 |
| Coal | 9 | |



*A*



*B*

McDONALD & COTTLE MINE NEAR THERMOPOLIS, WYO.

*A*. Entrance. *B*. Coal bed.

An area of 1 square mile underlain by a coal bed 14 feet thick would contain 14,000,000 tons of coal, an amount far exceeding the total product of the Red Lodge mines during the past fourteen years. Of course, there is always a loss in working, and in an area of broadly lenticular coal deposits allowance must be made for a certain amount of variation in thickness. In an area underlain by 30 feet of coal, 1 square mile would contain 30,000,000 tons, or supposing that on an average only one-half that thickness were found, there would be 15,000,000 tons of coal. A determination of the productive capacity of the entire Thermopolis district was not undertaken in the present reconnaissance. The total coal acreage of this region can be only rudely estimated, for no systematic prospecting has ever been conducted, but coal outcrops may be seen along the strike of the beds for several miles, and as the dip is uniform and moderately low the field is undoubtedly large.

### NO WOOD DISTRICT.

An opening has been made in a coal bed which outcrops near the base of a prominent hill at the head of Bud Kimball Draw, 14 miles southwest of Tensleep, Wyo. Coal is not mined here regularly, but many of the settlers along the No Wood Creek Valley obtain their fuel supply from this place. The coal bed, which occurs in the lower part of the Laramie and associated formations, has an aggregate thickness of about 6½ feet, consisting of four benches separated by a parting of bony coal and brown leaf-bearing shale.

*Section of coal-bearing beds near head of Bud Kimball Draw, Wyoming.*

| | Ft. | In. |
|---|---|---|
| Brown leaf-bearing shale | | 0 |
| Very impure coal | | 10 |
| Gray sandstone | | 4 |
| Coal containing thin layers of bone | 3 | 6 |
| Brown leaf-bearing shale | | 10 |
| Bony coal | | 3 |
| Coal | | 9 |
| Bony coal | | 4 |
| Coal | 1 | 6 |
| Bony coal | | 6 |
| Coal | 1 | |
| Total | 9 | 10 |

About 3 miles southeast of Bell's ranch, on No Wood Creek, there is a small coal district. The principal interest attached to this locality is the fact that the deposits are contained in the basal sandstones of the Cloverly formation, less than 50 feet above the Morrison formation. The coal has been prospected at frequent intervals for 2 or 3 miles along the strike, which here trends east-southeast, but at present operations are confined to one opening, known as the Diehl & Bell mine. The deposit consists of two benches each 4 feet thick, separated by a 2-inch layer of dark-colored shale. In appearance the coal is dark, with dull, earthy luster, conchoidal fracture, and resembles closely a carbonaceous shale. The accompanying section will show the thickness and relative position of the coal seams.

*Section at Diehl & Bell mine, near Tensleep, Wyo.*

| | Ft. | In. |
|---|---|---|
| Coal | 4 | |
| Dark-gray slate | | 2 |
| Coal | 4 | |

### BASIN DISTRICT.

The next locality of coal outcrops to the northwest is locally known as the Basin district, because of its nearness to Basin, the county seat of Bighorn County. There are two small mines in this district; the larger one, located near the mouth of No Wood Creek, about 5 miles southeast of Basin, is owned by Rogers & Gapen. It has been worked continuously for about five years, although coal has been taken from this opening for more than a decade. The deposit has a measured thickness of 5 feet and contains many thin, slaty partings, which, although numerous, are in total thickness insufficient to render the deposit unfit for economic development. Since 1900 the product has averaged about 400 tons a year, with a market value of $2 per ton at the mine. The character of the seam is illustrated in the following section:

*Section at the Rogers & Gapen mine, near Basin, Wyo.*

| | Ft. | In. |
|---|---|---|
| Coal | 1 | 1 |
| Impure coaly shale | | 1 |
| Coal | | 8 |
| Black shale | | 2 |
| Coal | | 7 |
| Dark-gray clay | | 6 |
| Coal | | 5 |
| Coaly shale | | 2 |
| Coal | | 11 |
| Dark-gray clay | | 2 |
| Coal | 1 | 3 |

There is another mine in this district, located about 1 mile southwest of Basin, owned by G. N. Mecklen. The bed is 2½ feet thick, with a 6-inch shaly parting near the base. The coal is contained in sandy beds, which here dip to the south at such a steep angle that the limit of economic mining will soon be reached. This mine produces about 600 tons a year, which is consumed by the residents of Basin and the Bighorn River Valley. The mine is poorly improved and the bed is too thin to warrant any considerable development, as is shown by the following section:

*Section of Mecklen mine, near Basin, Wyo.*

| | Ft. | In. |
|---|---|---|
| Coal | 2 | |
| Dark-gray slate | | 6 |
| Coal | | 6 |

Along the exposed area of the coal-bearing formation, between Gray Bull and Shoshone rivers, some prospecting has been done, resulting in the location of a few thin coal deposits, all of which are under the limit of a profitable working thickness.

### GARLAND DISTRICT.

About 3 miles northwest of Garland there is a small coal-mining district. The coal occurs in sandstones comprising the lower portion of the coal-bearing measures. The productive beds outcrop in low sandstone ridges that dip gently southwestward and soon pass under higher beds toward the center of the basin. Two mines are worked at present, one by the Wyoming Coal and Fuel Company and the other by the Garland Coal Company. They are located within a few yards of each other and both are working on the same coal horizon, though a comparison of the deposits at the two openings shows considerable variation. At the former the seam is composed of an upper and a lower bench containing two distinct varieties of coal. In the upper bench, which is 2 feet 2 inches thick, the coal is black, with a bright luster. It occurs in layers and breaks into blocks. The lower bench, which is 1 foot 4 inches thick, consists chiefly of a brown, coaly shale with numerous thin layers of coal. The proportion of shale to coal varies, the former sometimes disappearing entirely. The two benches are not separated by a layer of slate, as is usually the case at this horizon, but the sudden change in the character of the material indicates the dividing line.

At the Garland Company's mine a slightly different section is observed. Here there is an increase in the thickness of the upper bench, but in quality there appeared to be no essential points of difference. In the lower bench the coal predominates over the coaly shale. The change is due to the rapid thickening and uniting of the thin coal layers. The product of both benches resists weathering fairly well for a lignite. Midway between the two mines the Wyoming Coal and Fuel Company has opened at this horizon a trial pit, which exhibits 4 feet 3 inches of coal without parting. The coal of the lower bench is entirely free from shale, and in its physical properties appears superior to that of the upper bench. The beds in this region have uniformly low dips and the coal could be easily mined. The mines are less than 1 mile from the Mantua switch on the Toluca-Cody branch of the Burlington and Missouri River Railroad, so that a side track might be constructed at small cost, which would enable the companies to ship their coal. The following measurements were made at the three different openings along the strike:

*Section at the Wyoming Coal and Fuel Company's mine, Garland, Wyo.*

| | Ft. | in. |
|---|---|---|
| Coal | 2 | 2 |
| Brown carbonaceous shale with streak of coal | 1 | 4 |

*Section at the Garland Coal Company's mine, Garland, Wyo.*

| | Ft. | in. |
|---|---|---|
| Dark-gray clay | 2 | |
| Coal | 3 | 6 |
| Coal with streaks of carbonaceous shale | 2 | 6 |

*Section at coal prospect, made by Wyoming Coal and Fuel Company, Garland, Wyo.*

| | Ft. | in. |
|---|---|---|
| Dark-gray compact clay | 4 | |
| Coal | 4 | 3 |

### SILVER TIP DISTRICT.

This is a small district located on Cottonwood Creek on the north side of the divide between Clark Fork and Shoshone River. The deposit has been prospected at several places in the immediate vicinity, but the principal opening, the Silver Tip mine, is in sec. 29, T. 58, R. 100. Here considerable coal has been taken out for the last three years, chiefly to supply the ranch trade of Clark Fork Valley. The total thickness of the bed is 5 feet, including two partings of impure coal and a thin layer of soft light-colored clay. The main entry is driven in about 125 feet from the outcrop, and throughout this distance the character of the coal bed fixed appears to be uniform, and analysis of this coal shows a moderate amount of carbon and volatile matter with relatively low percentages of water and ash. A section of the coal bed at the Silver Tip mine is here given:

*Section at Silver Tip mine on Cottonwood Creek, Wyoming.*

| | Feet. |
|---|---|
| Gray compact sandy clay | 4 |
| Brown leaf-bearing shale | 3 |
| Coal | 5 |
| Gray sandstone | 6 |
| Impure coal with streaks of leaf-bearing shale | 2 |
| Dark-colored sandstone | 5 |

### BENTONITE.

The variety of clay known as bentonite was first described in 1898, by the late Prof. W. C. Knight, of the Wyoming State School of Mines, and since that time several articles have appeared in scientific journals, a list of which are given below.[a] The mineral is a hydrous silicate of alumina, possessing peculiar physical properties. It occurs at various horizons in the Colorado formation and in the overlying Pierre shale. Fresh bentonite has a pale yellowish-green color, but on exposure it changes to a light-cream tint. It is a fine-textured, soft, massive variety of clay, which is unctuous to the touch and which, upon the addition of water, forms an emulsion. It is characterized by its unusual power of absorption, having the capacity of absorbing three times its weight of water. In a comparative test it is reported to have taken twice as much nitroglycerine as infusorial earth. When first taken from the quarry, it breaks with conchoidal fracture, but upon exposure loses this property and crumbles to a light yellowish powder resembling corn meal. The specific gravity of this clay, when fresh, is 2.18. Its resemblance to ehrenbergite of Germany has been pointed out by Mr. Knight and its relationship to montmorillonite by Mr. Read. The clay from different localities varies somewhat in composition, but in general it is quite uniform in a single deposit.

This clay has been used with success in various ways, chiefly in the manufacture of paper. It has also been used as a soap. It is regarded valuable as a packing for a special kind of horseshoe and as a diluent for certain powerful drugs in powdered form. Dr. E. E. Slosson, of the University of Wyoming, has recommended its use as a retarder for certain kinds of plaster.

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[a] Knight, W. C., Eng. and Min. Jour., vol. 63, 1897, pp. 600-601; Knight, W. C., Eng. and Min. Jour., vol. 66, 1898, p. 491; Merrill, George P., Ann. Rept. U. S. Nat. Mus., 1899, pp. 340, 348; Slosson, E. E., Tenth Ann. Rept. Wyo. Coll. Agric. and Mech., 1900, Extract. p, 14; Read, Thomas T., Eng. and Min. Jour., vol. 76, 1903, pp. 48, 49; Darton, N. H., Description of Newcastle district: Geologic Atlas U. S., folio No. 107, U. S. Geol. Survey, 1904, pp, 5, 9; Merrill George P., The Non-Metallic Minerals, 1904, pp. 233, 243; Fisher, C. A., Bull. U. S. Geol. Surv. No. 260, 1905, pp. 559-563.

Bentonite deposits were observed at many localities in the Bighorn basin, where they usually occur in the Colorado shales about 100 feet below the Mowry beds, although in one locality, near the Silver Tip coal mine, they are reported in beds above the Colorado formation. One of the most extensive deposits of bentonite observed in this district is on Dry Creek, about 8 miles east of Frannie, Wyo. Here the bentonite is in the black shales of the lower part of the Colorado formation, a short distance below the Mowry beds, which are well developed at this place. The deposits have a total thickness of 11 feet, distributed throughout a vertical range of 100 feet. The thickest layer is about 7½ feet. Below the bentonite, beds of dark shale abound, and above are lighter shales containing bands of iron concretions. The material at this locality is a gray, fine-grained, massive clay, with green and yellow tints and is apparently of good quality throughout. The thin seams of gypsum, sometimes associated with the clay, are present though not conspicuous. The following section will show the approximate position of the different deposits at this place:

*Section of a portion of the Colorado formation on Dry Creek, Wyoming.*

| | Feet. |
|---|---|
| Bentonite | 2 |
| Dark fissile shale | 12 |
| Bentonite | 7½ |
| Shale | 30 |
| Bentonite | 1 |
| Shale containing thin layers of bentonite | 50 |

Near the head of Dry Gulch, about 5 miles north of Cowley, Wyo., a 1½-foot layer of bentonite is found near the top of the Colorado formation. The following section shows the materials above and below the clay:

*Section taken from head of Dry Gulch, Wyoming.*

| | Feet. |
|---|---|
| Black shale capped by brown sandstone | 6 |
| Bentonite | 1½ |
| Black fissile shale | 20 |

During the last field season deposits of a clay possessing properties similar to bentonite were discovered in the lower part of the coal-bearing measures; also in the overlying Wasatch formation. Those in the former are associated with thin deposits of coal and coaly shale in sandy beds outcropping at the head of Bud Kimball Draw, 12 miles southeast of Tensleep, Wyo. A section of the deposit is here given:

*Section of bentonite at head of Bud Kimball Draw, Wyoming.*

| | Feet. |
|---|---|
| Brown leaf-bearing sandy shale with streaks of coal | 2 |
| Dark-gray clay | 4 |
| Bentonite | 6 |
| Light-gray clay | 6 |
| Gray sandstone with carbonized wood particles | 1 |
| Impure coal | 1 |
| Gray sand. | |

In the badlands of the Wasatch formation, on the southern side of Cottonwood Creek, about 10 miles southeast of Meeteetse, an impure bentonite occurs.

### GYPSUM.

The gypsum deposits of the Bighorn basin are mainly in the Chugwater formation. They occur also in the lower part of the Sundance formation, and at one locality a deposit 8 feet thick was observed in the upper part of the Morrison formation. In the Chugwater red beds there is usually a gypsum layer 30 to 40 feet thick near the top of the formation and generally one of equal thickness at or near its base. Along the southern side of the basin the gypsum at the base of the red beds is absent. Thinner beds of gypsum are found at various horizons in the Chugwater formation, but these appear to be of local deposition. In most places where the gypsum has been carefully examined it is apparently of good quality, though no analyses have been made to determine its exact chemical nature. It is a white, compact, massive variety and generally occurs in beds that are free from partings. The following section, taken on Trail Creek northwest of Cody, will show the position of the gypsum in the upper part of the Chugwater red beds:

*Section of a portion of the Sundance and underlying Chugwater formation on Trail Creek, Wyoming.*

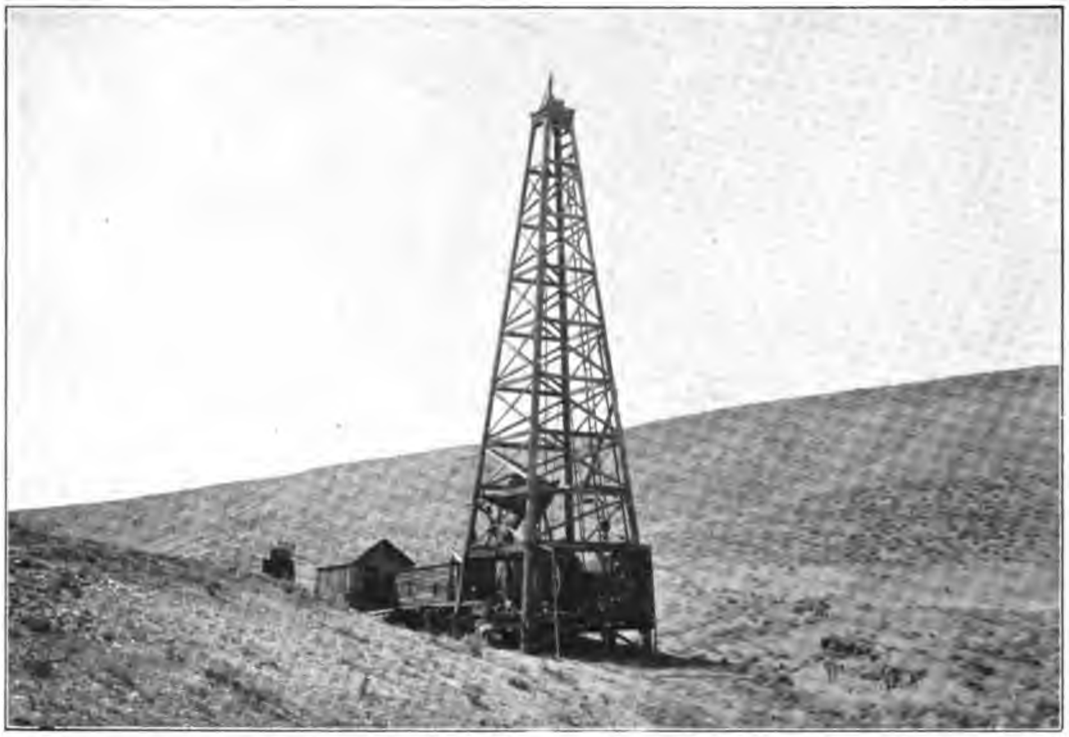
| | Feet. |
|---|---|
| Green shale containing thin limestone layers (Sundance) | 3½ |
| Red sandy shale containing thin layers of gypsum (Chugwater) | 12 |
| White massive gypsum | 30 |
| Red sandstones (red beds). | |

About 10 miles south of Cody a deposit of gypsum was observed in the upper part of the Morrison formation. The following section shows its relative position:

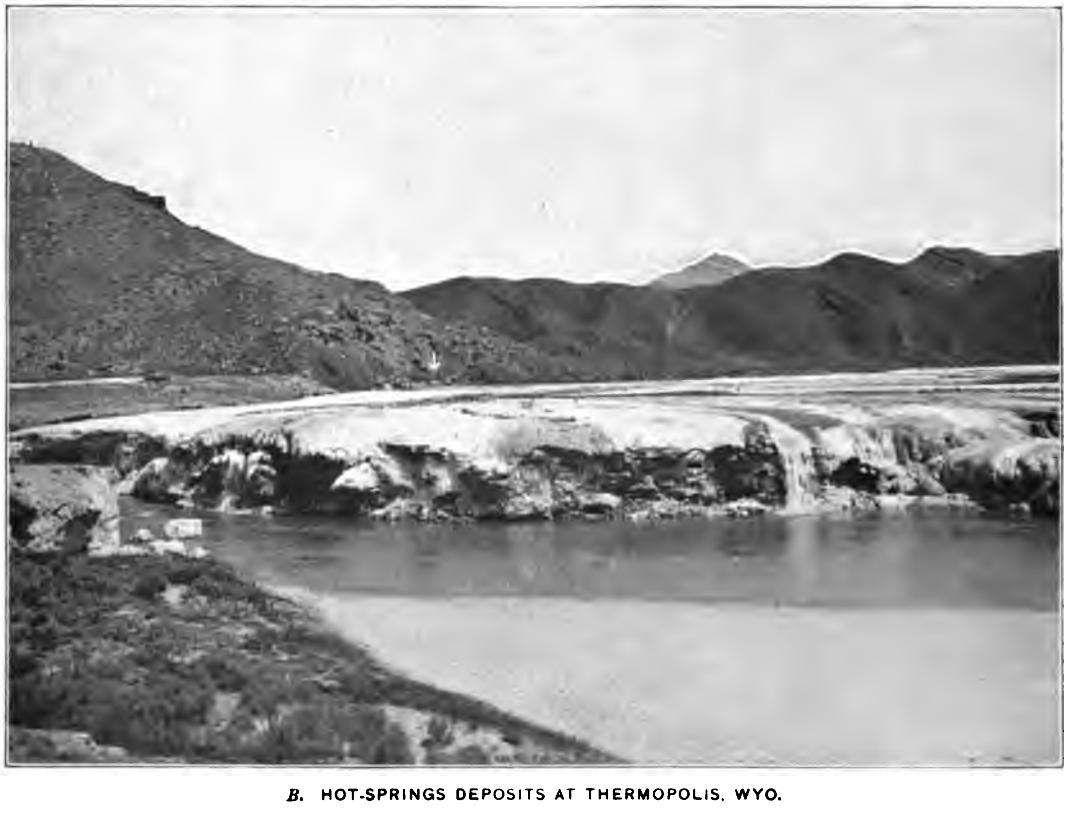
*Section of a portion of the Morrison and overlying Cloverly formation south of Cody, Wyo.*

| | Feet. |
|---|---|
| Brown, coarse-grained, cross-bedded sandstone (Cloverly) | 60 |
| Reddish sandy shale with thin gypsum layers | 25 |
| White massive gypsum | 8 |
| Reddish sandy shale with thin gypsum layers | 15 |

Though there are extensive deposits of gypsum throughout this area no attempt has been made to utilize the product except in a very small way. There is a stucco mill about 10 miles northeast of Windsor post-office, Wyo., in the southern part of Montana, where plaster is manufactured from a gypsum deposit near the base of the Chugwater red beds. The beds mined at this place are about 15 feet thick, and the product is of good quality. The material is ground and placed in ovens, where it is calcined at a red heat in order to drive off the chemically combined water. A retarder is then added to prevent it from hardening too quickly when water is applied. After this it is mixed with hair and placed in barrels ready for shipment. The entire process of converting the gypsum into stucco is relatively simple and inexpensive. The finished product of this mill is sold at Bridger at $12 a ton, but the output is not large.



*A.* OIL WELL AND DERRICK NEAR BONANZA, WYO.



*B.* HOT-SPRINGS DEPOSITS AT THERMOPOLIS, WYO.

## OIL AND GAS.

*Bonanza oil field.*—Several attempts have been made to obtain oil from the Cretaceous shales throughout the Bighorn basin, but generally without success. About three-fourths of a mile southwest of Bonanza, near the axis and at the northern end of a small anticline in the Colorado formation, several oil seeps furnish a small amount of oil. The oil is from a thin-bedded sandstone underlying the Mowry beds of the Colorado formation. This surface indication has caused many persons to believe that oil in paying quantities might be obtained by drilling, and consequently several deep borings have been made in this region (Pl. XV, *A*). None of these have been successful, and at present all exploration has ceased. Oil from the Bonanza district has been studied by E. E. Slosson, of the University of Wyoming, and the distillation of the product is given below:

*Distillation of Bonanza petroleum.*[a]

| No. | Boiling point. | | Specific gravity. | Degree Baumé. | Flashing point. | | Burning point. | |
|---|---|---|---|---|---|---|---|---|
| | °C. | °F. | | | °C. | °F. | °C. | °F. |
| 1 | 60-157 | 140-314 | .762 | 53.5 | Below 15 | Below 59 | Below 15 | Below 59 |
| 2 | 157-200 | 314-392 | .792 | 46.5 | 18 | 64 | 36 | 97 |
| 3 | 200-237 | 392-459 | .822 | 40.3 | 38 | 100 | 78 | 172 |
| 4 | 237-273 | 459-523 | .843 | 36.1 | 82 | 180 | 108 | 226 |
| 5 | 273-297 | 523-567 | .853 | 34.1 | 108 | 226 | 132 | 270 |
| 6 | 297-329 | 567-624 | .867 | 31.4 | 121 | 250 | 161 | 327 |
| 7 | 329-371 | 624-715 | .876 | 29.8 | 46 | 115 | 162 | 323 |
| 8 | 371-391 | 715-736 | .861 | 36.6 | Below 15 | Below 59 | 52 | 125 |
| 9 | 391-340 | 736-646 | .849 | 34.8 | Below 15 | Below 59 | 48 | 118 |
| Crude | | | .850 | 34.6 | 19 | 66 | 33 | 91 |

[a] 280 cm.$^3$ distilled in 10 per cent fractions.

A deep boring for oil was made at the mouth of Cottonwood Creek, on Shoshone River, near Cody, Wyo., but no oil was obtained. The well is located on the western slope of a small anticline in Colorado shale.

*Byron gas field.*—Plans are now being made to sink a deep well on the western side of a broad anticline, along the axis of which a small area of Pierre shale is exposed. Shoshone River crosses the southern end of the anticline and has cut for some distance into the shale. In the low valley of this stream near the center of the anticline there are places where gas escapes in considerable quantity from the alluvial sands. It probably is derived from the underlying shales of the Pierre formation. The gas burns readily, but its quality was not ascertained. The boring which is now proposed will doubtless demonstrate whether or not gas is present in sufficient amount to warrant development.

About 3 miles east of Basin, Wyo., a small well is being dug in the Pierre shale for the purpose of finding gas. The present depth of the well is about 100 feet and an appreciable amount of gas has already been obtained. A small company has been organized and the work will be continued.

## BUILDING STONE.

*Sandstone.*—Several varieties of building stone are found in the various formations exposed in the Bighorn basin, but at present only a small amount is used. These varieties comprise sandstone, limestone, marble, and granite. A sandstone used for building occurs in the upper part of the Benton formation, and in some districts the Cloverly formation furnishes a sandstone of moderate firmness and pleasing color. The Chugwater formation also contains layers of sandstone which, on account of their rich red color, have been used as an ornamental stone. The sandstones of the Laramie and associated formations are generally too soft to be used in construction work.

*Limestone.*—Limestone, although abundant, is not generally used as a building material. A very pure variety of limestone, resembling marble, occurs at the top of the Madison formation. In the Bighorn Mountains this stone has been quarried for trial. It is of a light-cream color, fine grained, uniform in texture, and apparently of good quality.

*Granite.*—In Shoshone Canyon, west of Cody, granite is exposed which might prove to be of good quality for building stone. It is a dark gray, moderately coarse-grained variety and appears to be firm and durable. The material is to be used in the large Government dam across Shoshone River, now in course of construction.

## GRAVEL.

The later Quaternary gravels along the south side of the Shoshone River Valley have been used by the Burlington and Missouri River Railroad Company as roadbed material. Gravel especially well suited for this purpose is found about 2 miles west of Garland. Here a switch has been built and a large amount of gravel is taken out. The gravels of this region are dark colored, owing to the presence of a large amount of volcanic material.

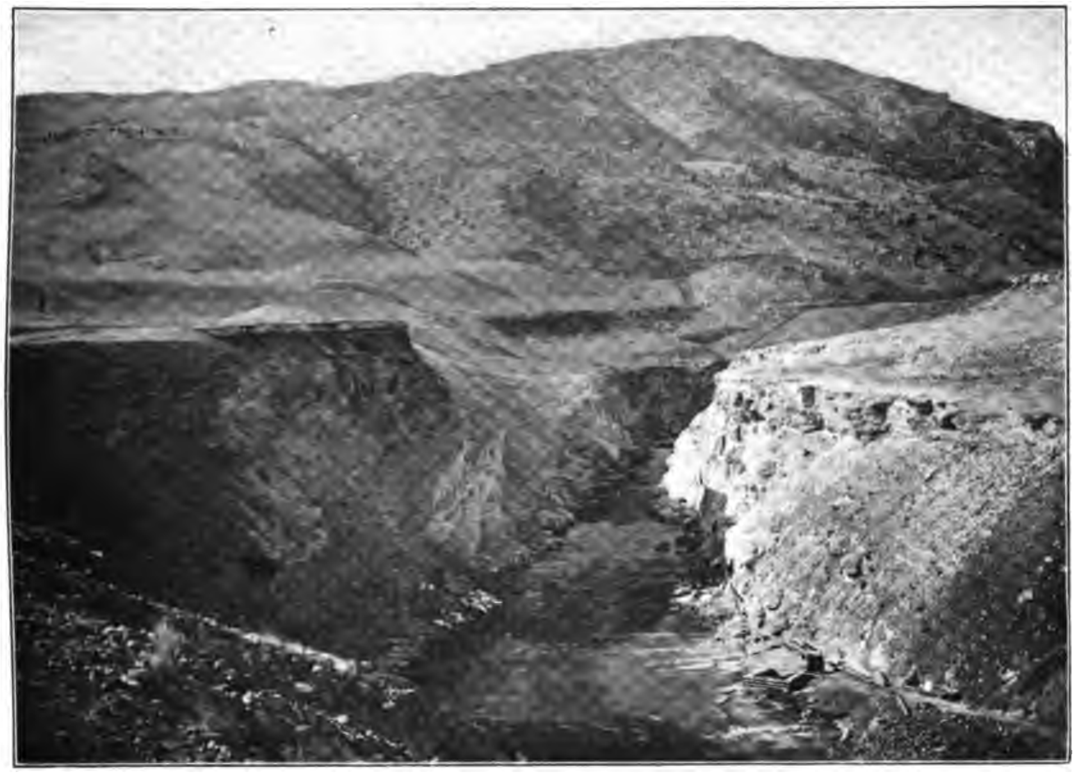
## FIRE CLAY.

The Cloverly formation throughout this general region has the usual interstratified beds of clay and shale which in other districts are of refractory character, suitable for fire clays of good quality. None of these clays throughout the basin have been tested, but it is possible that they may prove to be of good quality.

## GOLD.

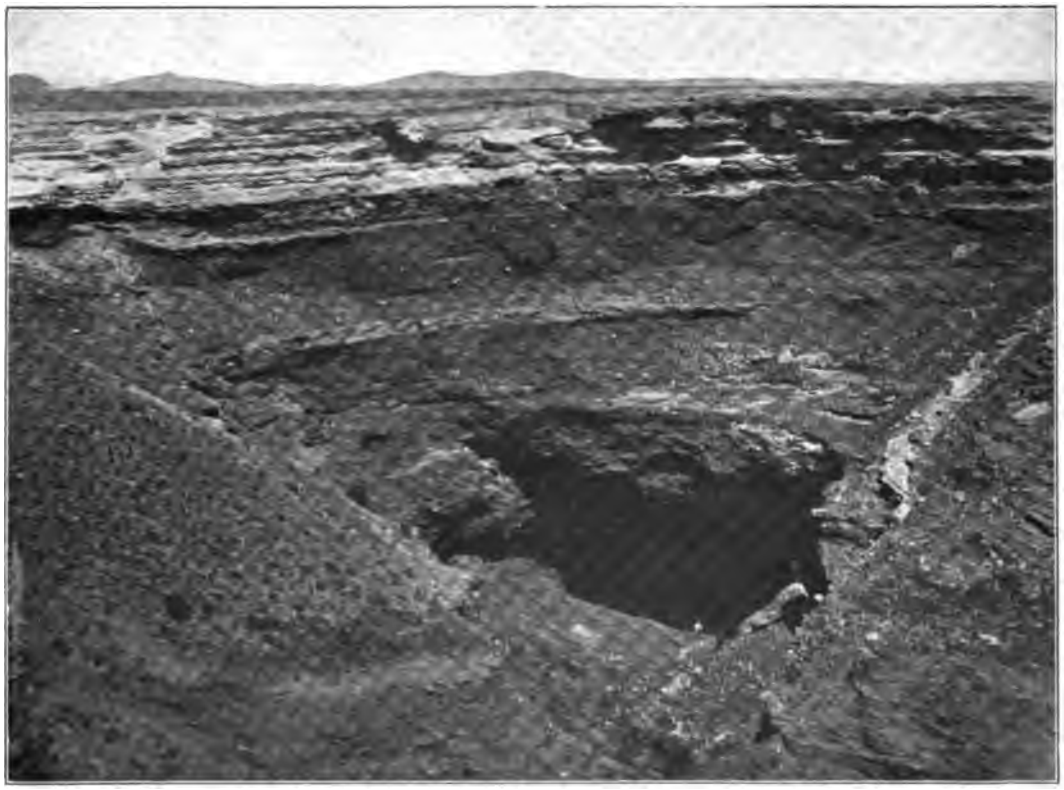
*Bald Mountain district.*—During the past decade various attempts have been made to develop gold mines in the vicinity of Bald Mountain, but the results have not been encouraging. The gold occurs in the basal gravels of the Deadwood formation, especially where these gravels have been mixed with disintegrated portions of the underlying granite and redeposited as a valley filling. The gold is fine grained and free, but values are low and its distribution throuhgout the gravels is apparently irregular. The highest assays reported are $2 a ton, but the amount is usually much less.

*Bighorn basin region.*—Gold is mined from placers along Clarks Fork, in the vicinity of Clark, and on Shoshone River below the mouth of Alkali Creek. The output has never been large at either of these localities.



*A*. SHOSHONE RIVER AT CODY HOT SPRINGS.

Showing Quaternary gravels and extinct geyser cone.



*B*. SINK HOLE IN GEYSER DEPOSITS.

## MINERAL WATERS.

### CODY HOT SPRINGS.

*Description.*—About 3 miles west of Cody, in the bed of Shoshone River, there are a number of warm mineral springs. Formerly springs of this character occurred on both sides of the river, but at present they are confined mainly to the north side, where, along the water's edge, within a distance of about 200 feet, five or six springs are found. The water issues from crevices in Embar limestone immediately underlying the Chugwater red beds, which here dip eastward at an angle of about 15°. These beds are overlain by a deposit of Quaternary gravel 25 to 30 feet thick, capped by about 20 feet of travertine. Near the middle of the stream is a large spring which flows vigorously and is evidently under considerable pressure. During times of low water this spring is very noticeable, but in the flood season it is entirely covered by the river water. No analysis has been made of the spring water, but it evidently contains a large amount of hydrogen sulphide and probably some sulphuric acid. It is also otherwise considerably mineralized. The water is clear, warm, and emits a strong sulphurous odor. In the warmest spring it has a temperature of 98°. The water is diverted into pipes which lead to a sanitarium, where it is used both for bathing and for medicinal purposes. Closely associated with the springs are vents or crevices in the rock, from which large volumes of hydrogen-sulphide gas escape, and the limestone immediately surrounding these vents is considerably altered.

The geologic structure of this region is relatively simple, as is shown in cross section No. 3 of Pl. IV. The springs occur at the lower end of Shoshone Canyon, at the base of Rattlesnake Mountain, which is a moderately broad anticlinal ridge branching from the front range of the Absaroka Mountains. The anticline has long, gradual slopes on the east and steep dips on the west, and it rises to an altitude of about 8,500 feet. It is noteworthy that the greatest thermal activity has taken place on the side of lowest dips. Shoshone Canyon exposes the structure of the uplift down to and into the crystalline rocks.

*Hot-spring deposits.*—Hot-spring deposits occur at different levels in Shoshone Canyon and at its upper and lower end, far above the present level of the river. On the north side of the river, just below the mouth of Shoshone Canyon, there is a broad travertine terrace covering several acres, and smaller areas are found along the east side of Cedar Mountain from Shoshone River southward for about 2 miles. The distribution of these deposits is shown on the geologic map, Pl. III. A number of extinct geyser or hot-spring cones occur. The most prominent of these on the south side of Shoshone River is shown on Pl. XVI, *A*. On the north bank of the river, a short distance north of the sanitarium, there is an empty crater about 70 feet in diameter and 40 feet deep (Pl. XVI, *B*), indicating the position of a hot pool, and a short distance northeast of this there is a smaller crater of similar nature.

*Source of water.*—It is difficult to ascertain definitely the source of water of the Cody hot springs, but the flow is probably not derived from the formation in which the springs occur. Two water-bearing horizons underlie the Embar limestone—the Tensleep and Deadwood formations—and the water is probably derived from one of these sources. Under these conditions its only means of escape to the surface is through fractures in the strata along the side of the arch. If the water is derived from the Tensleep formation a very high heat gradient of the earth's crust in this region must be assumed in order to account for the temperature of the spring water, for this formation is not deeply covered by overlying beds between the area where the water passes underground and the point of its reappearance at the springs. If the water comes from a deeper-seated source, such as the Deadwood formation, its temperature can be satisfactorily accounted for. The sandstone at the base of the Deadwood, which is the only water-bearing horizon of the formation, is about 2,200 feet below the surface at the springs. Assuming that the mean annual temperature at Cody is 50° and that there is an increase in temperature of 1° for every 50 feet underground below the first 50 feet, the temperature of the earth's crust at a depth of 2,200 feet would be about equal to the temperature of the spring water. It seems probable, therefore, that the water of the Cody hot springs is derived from the base of the Deadwood formation and that it rises to the surface under hydrostatic pressure, through fractures in the strata along the base of the Rattlesnake Mountain anticline.

### THERMOPOLIS HOT SPRINGS.

At Thermopolis, on Bighorn River in the southeastern part of the Bighorn basin, there is a hot mineral spring the flow of which has been variously estimated at from 3,000 to 4,000 gallons a minute. Calcium carbonate is the principal ingredient of the water, while magnesium sodium and calcium sulphate are present in smaller amounts. (Pl. XV, *B*, p. 58.) An analysis of this water made by Prof. E. E. Slosson, of the University of Wyoming, is here given:

*Composition of the waters of Thermopolis Hot Springs, Wyoming.*

| | | | |
|---|---|---|---|
| $SiO_2$ | 4.986 | $CaSO_4$ | 13.156 |
| $Fe_2O_3$ and $Al_2O_3$ | .227 | $CaCO_3$ | 40.454 |
| $KCl$ | 10.249 | $NaCl$ | 26.195 |
| $Na_2SO_4$ | 15.110 | | |
| $Mg_2SO_4$ | 19.443 | | 129.820 |

There are two sanitariums and a large plunge located near the spring, and the place is rapidly becoming a popular health resort for people of northwestern Wyoming. The Thermopolis hot springs have been described by Mr. N. H. Darton.[a]

### WARM SPRINGS IN BLACK CANYON.

Warm springs are reported from Sheep Canyon in the northeastern part of the basin, and farther up Bighorn River at the upper end of Black Canyon there is a small spring of mineral water which is noticeably warmer than the river water.

### SULPHUR.

Sulphur occurs in local deposits on the southern side of Shoshone River, at the lower end of Shoshone Canyon, and along the western side of Sulphur Creek for about 2 miles above its mouth. It was deposited by heated waters and gas from the numerous hot springs that once existed in this region. A large amount of prospecting has been done, and development of this resource is at present being considered. The material appears to be of excellent quality, but there is some doubt whether it occurs in sufficiently large quantities to warrant extensive development. Sulphur also occurs in hot-spring deposits at Thermopolis, Wyo.

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[a] Geology of the Owl Creek Mountains, etc.: U. S. Senate Doc. No. 119, 59th Congress, 1st session.

## CLIMATE.

There is a wide range of climate in the Bighorn basin region, corresponding mainly to differences of altitude. On the high mountains surrounding the basin heavy snows usually begin early in September and continue until April, while in the center of the basin snow rarely lies on the ground for any great length of time and only a few days of cold weather occur during the winter months. Very few meteorologic data concerning the climatic features of the mountainous regions are available, but in several places in the basin systematic observations have been made by the Weather Bureau since 1898. The following table gives a record of the monthly and annual mean temperature at Basin, Wyo., for a period of five years, 1898 to 1903, inclusive, with the exception of 1901:

*Records of the monthly and annual mean temperature, etc., in round numbers, at Basin, Wyo.*

| Year. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Annual. | | | Killing frost. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Mean. | Extremes. | | Last in spring. | First in autumn. |
| | | | | | | | | | | | | | | *Max.* | *Min.* | | |
| 1898 | ...... | ...... | ...... | ...... | ...... | ...... | 73 | ...... | ...... | 41 | 28 | 12 | ...... | ...... | ...... | ........ | ........ |
| 1899 | 18 | 2 | 20 | 46 | 55 | 68 | 74 | 70 | 59 | 43 | 34 | 12 | 42 | 107 | −51 | May 5 | Sept. 7 |
| 1900 | 14 | 12 | 30 | 45 | 60 | 72 | 78 | 74 | 60 | 48 | 30 | 27 | 46 | 114 | −36 | Apr. 18 | Sept. 15 |
| 1902 | 12 | 23 | 36 | 46 | 61 | 67 | 74 | 73 | 59 | 49 | 32 | 20 | 46 | 107 | −39 | May 4 | Sept. 18 |
| 1903 | 22 | 16 | 34 | 46 | 55 | 70 | 74 | 73 | 61 | 48 | 30 | 22 | 46 | 107 | −17 | June 9 | ........ |
| Average. | 16 | 13 | 30 | 46 | 58 | 69 | 74 | 72 | 60 | 46 | 31 | 19 | 45 | ...... | ...... | ........ | ........ |

## RAINFALL.

There is a moderate amount of rainfall in summer throughout this general region, especially in the mountainous districts, where it has been variously estimated from 30 to 40 inches. On the lower lands in the interior of the basin arid conditions prevail. Here the snowfall is light and the amount of rain small, the average annual precipitation varying from 3 to 10 inches. During the summer there are a few heavy showers, but they are usually of short duration. A record of the monthly and annual precipitation at Basin, Wyo., for a period of six years, 1898 to 1903, inclusive, is given in the following table:

*Records of the monthly and annual precipitation at Basin, Wyo.*

| Year. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1898 |  |  |  |  | 2.28 | 0.80 | 0.10 | 0.14 | 0.06 | 1.13 | 0.20 | 0.10 |  |
| 1899 | 1.84 | 3.56 | 1.94 | 0.13 | 0.57 | 0.53 | 0.22 | 0.27 | 0.23 | 0.38 | 0.00 | 0.27 | 9.94 |
| 1900 | 0.08 | T. | T. | 1.06 | 0.58 | 0.29 | 0.06 | 0.15 | 0.31 | 0.36 | 0.02 | T. | 2.91 |
| 1901 | 0.00 | 0.16 | T. | 0.36 | 1.50 | 1.46 | 0.05 | 0.83 | 0.25 | 0.12 | 0.17 | 0.85 | 5.84 |
| 1902 | 0.16 | 0.14 | 0.27 | 0.85 | 0.61 | 0.24 | 0.21 | 0.04 | 0.08 | T. | 0.03 | T. | 2.63 |
| 1903 | T. | 0.21 | T. | 0.86 | 0.81 | 0.62 | 0.96 | T. | 0.26 | T. | T. | 0.06 | 3.78 |

T.=Trace.

## CULTURE.

Settlement here, as elsewhere, is determined by geologic and climatic conditions. Along the larger streams, where water is available, settlements are numerous, while the higher badlands and grazing districts are practically uninhabited. The high mountains on both sides of the Bighorn basin are only thinly populated. The Bighorn Mountains, owing to the heavy snows, the long winters, and the prevalence of frosts during the nights of summer are not suited to farming and they are therefore without permanent inhabitants. During the summer, however, herders, prospectors, and forest rangers live in the mountains, but the season is very short. The same is true of the highlands on the eastern front of the Absaroka, Beartooth, and a portion of the Shoshone mountains. Here, for a short season during the summer, the summit of the range is occupied by ranchmen from the adjoining lowlands.

There are a number of medium-sized towns throughout the Bighorn basin. The town of Basin, located on the west side of Bighorn River in the east-central part of the basin, is a growing place of 600 to 800 inhabitants and the county seat of Bighorn County. It is located on the new branch of the Burlington Railroad now being built from Frannie to Worland, and is the central trading point for farmers living along a portion of the irrigated valleys of Bighorn and Gray Bull rivers and on Shell and No Wood creeks. The largest town in the basin is Cody, having a population of about 1,200. It is situated in the northwestern part of the district, near the southern termination of the Rattlesnake Mountains. It occupies a central location in a relatively large irrigated district, lying along Shoshone River and its more important tributaries. The warm mineral springs near Cody are used considerably for medicinal purposes and bathing and in consequence attract a few health and pleasure seekers to this place during the summer months. Cody is the base of supplies for the Shoshone irrigation project, which has its dam and storage reservoir about 5 miles above the town. Thermopolis is the third town in point of size in the Bighorn basin. It is situated on Bighorn River, in the southern part of the district, where it draws a large ranch trade from settlers along the irrigated lands of the neighboring streams. The most attractive feature of the place is the large hot springs which are extensively used for bathing and medicinal purposes and are rapidly becoming a favorite resort for the people of northwestern Wyoming. Meeteetse is a town of about 400 inhabitants, located on Gray Bull River in the western part of the basin, in the midst of both a grazing and irrigation district. It is the base of supplies for a large mining camp at Kirwin and is a central trading point for the southwestern part of the district.

Garland is a small town on the Burlington Railroad, in the northern part of the district, from which a large amount of freight is hauled to the interior of the basin. A short distance east of Garland are Byron, Cowley, and Lovell, small agricultural towns having a population of from 400 to 500. Worland, the terminus of the new Burlington road, is a growing town of 100 to 200 inhabitants, and along the eastern side of the basin there are several small trading points, including Shell, Bonanza, Hyattville, Tensleep, and Rome.

The valley of Shoshone River between Cody and Corbett is thickly settled by farmers. Between Corbett and Garland there are no ranches at present, but during the last year a number of claim shanties have been constructed on the land included under the proposed Government canal. Below Garland, in the vicinity of Byron, Cowley, Lovell, and Ionia, lies the most thickly populated district of the region. There are only a few scattered ranches along Bighorn River below Basin, but farther up a number of thickly populated districts occur and the entire valley is being rapidly settled. Along Shell, Paintrock, and Tensleep creeks ranches are numerous, and there are a few on Crooked, Beaver, Trapper, Bear, and Alkali creeks. Ranches occur at intervals along No Wood Creek, and on Dry Creek, about 15 miles above its mouth, there is a small German settlement around Germania. Gray Bull Valley is thickly settled throughout its entire course in the basin and on its largest tributary, Wood River, there are a number of well-improved ranches. The valley of Clark Fork, in the northwestern part of the area, is extensively farmed, and a few small places have been located on Newmeyer, Paint, and Pat O'Harra creeks. Along Owl Creek ranches occur at frequent intervals, but along Meeyero, Grass, and Gooseberry creeks they are generally 8 to 10 miles apart.

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